AIR QUALITY MONITORING AND EFFECTS OF EMISSIONS ON SOIL AND VEGETATION IN THE VICINITY OF THE TEXASGULF REFINERY COMPLEX

TIMMINS ONTARIO

(1970 – 1978)

April 1979

Ministry of the Environment
Ontario

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Sudbury

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realistic appraisal of mixing as measured by mean observed hydraulic retention time. It is likely that little mixing is applied to the outer portions of the digester and expected that solids deposition will occur in that region. Unfortunately, in this, and most other digesters, there is no provision for depth profile sampling in the area close to the walls to confirm these conclusions. It might also be noted that digester A transfer sludge was very poorly digested, being brown and displaying other raw sludge characteristics.

4.2 Primary Digester B

Primary digester B is the first-stage unit of a two stage digestion system.

Design and Operating Data

diameter	: 15.4 m	(50')
liquid sidewall depth	: 6.1 m	(20')
bottom cone height	: 1.9 m	(6.25')
volume	: 1229 m^3	(270,390 gal)
sludge feed rate (Q)	: 32.7 m^3/d	(7,200 gpd)
nominal hydraulic retention time (τ_N)	: 37.6 days	

Digester mixing is accomplished by a single mechanical mixer.

Mixer Data

Type	: Walker
Nameplate Power	: 7.46 kw (10 HP)
Propellor	: 4 blade; 61 cm (24") diameter turning at 294 rpm. Located 61 cm (24") below surface and served by a 76 cm (30") diameter, 4 m (13') long draft tube. Flow direction reversible.
Specific Applied Nameplate Power	: 6.07 kw/1000 m^3 (0.23 HP/1000 ft^3)

Digester "B" is equipped with a single roof sample port located 3 m (10') from the centrally mounted mixer.

SUMMARY

From 1970 to 1978, the Ontario Ministry of the Environment conducted a program to monitor air quality and to study soil and vegetation characteristics in the vicinity of the Texasgulf Canada Limited refinery complex near Timmins, Ontario. This time span covered a preoperational period, as well as six years of operation of the electrolytic zinc smelter and refinery.

Air quality data gathered at a site 1.6 km ENE of the zinc refinery indicated that monthly dustfall exceeded the Provincial Criterion on 6 occasions and total suspended particulate exceeded the Criterion on 6 out of 159 occasions. A lead peroxide sulphation plate network showed that there were only five occasions when the Provincial Criterion of 0.7 mg SO_3/100 cm^2/day was exceeded and these elevated levels were recorded at sites located in close proximity to the complex. A program of monitoring air quality utilizing mossbags was initiated in 1976 at 12 stations and expanded to 26 stations in 1977. Mapping of the data obtained from the mossbag monitors demonstrated that elevated concentrations of airborne zinc, copper, cadmium, lead and arsenic existed in the vicinity of the refinery (within 4 km) and that concentrations decreased with distance from the refinery. Criteria for these elements measured by this technique have not been established.

As part of the preoperational environmental study in the Timmins area, a number of vegetation surveillance plots were

established. Some realignment of the original program was necessary and 12 plots, each consisting of 20 aspen trees are presently maintained. The condition, insect injury, disease and growth of each tree are inspected regularly. Moderate to severe injury to the trees caused by insects (large aspen tortrix and aspen leaf roller) has occurred regularly in the area for a number of years and the fungous diseases, Fomes heart rot and Hypoxylon canker were common. From the data available, it was not possible to demonstrate that emissions from the Texasgulf operation have affected the growth of the trees. Plot site factors, pests and natural variability appear to have had a greater influence on the rate of growth of the trees than did the refinery emissions.

Injury to vegetation growing in the area immediately south and south west of the zinc refinery has occurred each year since refinery operations began (1973-1978). The injury zone is consistent with elevated concentrations of zinc, copper, cadmium, lead and arsenic in vegetation foliage, soil, snow samples and mossbags. It was concluded that acid mists and associated metals emitted from the cooling towers and the cellhouse of the zinc refinery were involved as causal agents of the injury. The zinc remelt furnace stack was also believed to have been involved prior to installation of a baghouse in 1974.

Sampling of soil and vegetation was initially conducted at each of the surveillance plots. In more recent years, samples of soil and foliage were also collected at several

additional locations nearer to the refinery. These latter samples contained elevated amounts of zinc, copper, cadmium, lead and arsenic. In 1977, an intensive soil sampling program in the vicinity of the Texasgulf complex was completed. Chemical analyses results were utilized in a computer mapping program (SYMAP) and the distribution of the elements around the refinery was mapped. The highest concentrations of the metals were measured in the area immediately south of the refinery and elevated concentrations of these elements were also found to be associated with the Ontario Northland Railroad siding east of the refinery where loaded railroad cars of metal concentrates are staged. Concentrations of the elements in the samples declined with distance from these two centres.

In 1975 and 1976, soil samples were collected from 3 depths (0-5, 5-10 and 10-15 cm) at 0,50 and 100 m from the property line of the Ontario Northland Railroad at 6 locations north and east of the Texasgulf operation. Elevated concentrations of zinc, copper, cadmium, lead and arsenic were found in the samples and concentrations decreased with distance from the railroad tracks and with sampling depth. Soil from the two most highly contaminated sites, as well as soil from 100 m south of the refinery, were subjected to a bioassay investigation. Corn plants were found to readily take up zinc and to a lesser extent cadmium and copper from the soil. Injury symptoms developed by the corn plants growing in this soil were comparable to those observed in field investigations. The bioassay tests demonstrated that emissions from the railroad operations as well as the emissions from the zinc refinery were available for uptake by plants and therefore are able to enter into the biosphere.

In conclusion, airborne emissions (zinc, copper, cadmium, lead and arsenic) from the zinc refinery are continuing to accummulate in soil and vegetation in the immediate vicinity of the refinery. Acute injury to several types of vegetation around the Texasgulf operation has been observed but growth of aspen trees was not shown to have been affected by the emissions in the presence of other environmental stresses. The contamination of soil and vegetation in the vicinity of the Ontario Northland Railroad tracks must also be considered in environmental studies conducted in the vicinity of the Texasgulf operation.

I INTRODUCTION

The ore body of Kidd Creek Mines (now owned and operated by Texasgulf Inc.) was discovered 23 km north of Timmins in 1964. Open mining of the deposit began in 1966 and underground mining was phased-in in 1973. The mine produces primarily zinc, copper and lead ores with silver, cadmium, tin, selenium and other minerals as secondary constituents. The ore is transported by rail from the mine site to the metallurgical site near Hoyle, about 20 km northeast of Timmins, Ontario (Figure 1). The concentrator at the metallurgical site, also owned by Texasgulf Inc., has operated since 1966 producing primarily zinc, copper and lead concentrates. In 1972, Texasgulf began operation of an electrolytic zinc plant (smelter and refinery) adjacent to the ore concentrator. Zinc and cadmium are produced in the refinery and sulphuric acid is recovered as a by-product of the roasting process. Recent annual production (average of

1976 and 1977) (8) at the metallurgical site included approximately 240,000 tons of copper concentrate, 455,000 tons of zinc concentrate and 35,000 tons of lead concentrate. Ninety-nine thousand tons of zinc metal, 1100 tons of cadmium in concentrates, 9.7 million troy ounces of silver in concentrates and nearly 200 tons of tin in concentrates are also produced annually (8).

Prior to the opening of the zinc plant, concern was expressed that widespread damage might result from emissions from operation of the refinery. The construction of the complex at the metallurgical site was conducted under the approval of the Ministry of the Environment with the intention that any emissions from the operation would meet Government of Ontario regulations with regard to ambient air quality.

In order to determine the environmental impact of the airborne emissions from the plant, the Ministry of the Environment initiated a program to monitor the air quality, and to study vegetation and soil characteristics in the area two years prior to the scheduled opening of the refinery. The preoperational survey was continued after startup was completed and was modified as the situation required (5). The present report summarizes the data obtained from the various surveillance programs conducted in the vicinity of the Texasgulf operation by the Ministry of the Environment between 1970 and 1978.

II AIR QUALITY MONITORING

A. Introduction

Since 1970, the Ministry of the Environment has conducted an

ambient air quality monitoring program in the Timmins area. In 1976 and 1977, as in previous years, the program consisted of a) total dustfall and total suspended particulate (TSP) measurements at a site near the Texasgulf smelter at Hoyle, and b) determination of sulphation rates during the growing season at various sites in the Timmins area. A program to monitor the distribution pattern of airborne metals utilizing mossbag monitors was initiated in 1976 and expanded in 1977. Data from the 1970 and 1975 surveys were published in an earlier report (5).

B. Dustfall Measurements

i) Sampling Method:

Dustfall consists of that portion of settleable particulate material in the air. The dustfall mass is comprised of particles mostly in the 25 to 100 micron diameter size range, with typical mass median diameters of 50 to 60 microns. Results are subject to considerable variability, largely due to recirculation and loss of material by air currents. The efficiency of the dustfall collector also depends on the amount of rainfall during the collection period. Nevertheless, dustfall sampling provides an estimate of the amount of airborne dust and data obtained from such measurements are used to identify dust problem areas. Dustfall samples can also be analyzed for various elements and compounds and some types of particulate matter (e.g. coal, coke, graphite, road dust, grain dust, wood chips) can be identified by optical microscopy.

Dustfall collectors are constructed of thick polyethylene and measure about 31 cm high and 15 cm in diameter. They are left exposed to the atmosphere for a period of about 30 days, and are usually secured to hydro poles at a height of approximately 3.6 to 4.0 metres above ground. Dustfall material collected during the exposure period is weighed and the results expressed in grams/metre^2/30 days. The Provincial criterion for total dustfall is 7.0 g/m^2/30 d. For a 12-month period, the criterion is 4.6 g/m^2/30 d.

ii) Total Dustfall:

The approximate location of the dustfall collector is shown in Figure 2. The site is approximately 1.6 km ENE of the Texasgulf complex. The collector was originally installed at that site in March 1973.

The results of the dustfall measurements for 1976 and 1977 are presented in Table 1. A considerable amount of data was lost due to a) vandalism of the dustfall collector, and b) invalidation of the sample as a result of contamination, tampering, etc. All values were below the Provincial criterion of 7.0 g/m^2/30 d. The dust levels were higher during the summer months, implicating dust from nearby roads as the main source of particulates. This result is consistent with data collected in 1975 and reported previously (4).

The following table summarizes the total dustfall data collected during the period March 1973 to December 1977 at that site:

SUMMARY OF TOTAL DUSTFALL DATA COLLECTED AT STATION 72014 FROM 1973 TO 1977

Year	No. of Samples	Max. Value ($g/m^2/30$ d)	Annual Mean ($g/m^2/30$ d)	Number of Times Above Criterion*	
				30 days	1 year
1973	6	4.9	3.5	0	0
1974	8	13.0	5.3	2	1
1975	10	10.2	5.3	4	1
1976	9	6.0	3.6	0	0
1977	8	6.5	3.8	0	0
Total	41	Max. 13.0		Total 6	2

* Ontario criterion: 30 days - 7.0 $g/m^2/30$ d
1 year - 4.6 $g/m^2/30$ d

The data indicate that during this period a total of 41 valid monthly samples were collected. Of these, 6 samples exceeded the Provincial monthly criterion. These excessive values were all recorded during the spring and summer period. Also, the annual objective was exceeded in 1974 and 1975, mainly as a result of the excessive values recorded during the spring and summer period.

iii) Elemental Analysis:

The contents of the dustfall collector were analyzed for arsenic, copper, iron, lead, nickel and zinc in 1976 and for copper, lead and zinc in 1977. The results are presented in Table 2. In 1976, although nearly all results were low, iron, zinc and lead accounted for the largest fraction in dustfall for the elements analysed. This finding is consistent with data obtained in 1975. One sample (February 1976) had

a lead content of 0.109 g/m^2/30 d. The Ontario criterion for lead in dustfall is 0.10 g/m^2/30 d. (This criterion is the only Provincial criterion for elements in dustfall). In 1977, the lead levels in dustfall were considerably lower (based on 4 samples only), whereas the levels of copper and zinc were approximately the same as the previous year.

The data indicate that the levels of the above elements in dustfall were very low, such that the largest fraction of dustfall is believed to have consisted of windborne soil and road dust. The Texasgulf complex (and related activities) appears to be a source of zinc and sometimes lead particulate of a size fraction large enough to settle as dustfall. This finding is consistent with the results of the mossbag and soil monitoring programs.

C. High Volume Air Sampling

i) Sampling Method:

This sampling method determines the mass concentration in micrograms/metre^3 (ug/m^3) of suspended airborne particulates by drawing a large air volume through a preweighed filter. Standard operation of the sampler involves air flow rates between 1.0 to 1.7 liters/min and the use of glass fiber filters. Normally, a sample is collected over a 24-hour interval every sixth day. In addition to the determination of the mass concentration (ug/m^3) of particulates, the filters can also be analyzed for a variety of elements and compounds.

ii) Total Suspended Particulates (TSP):

The approximate location of the hi-vol monitoring site is shown in Figure 2. The site is in the vicinity of the dustfall monitoring station and is approximately 1.4 km ENE of the Texasgulf complex. The sampler was originally set out at that location in 1973.

A summary of the total suspended particulate data collected in 1976 and 1977 is presented in the following table. The table also includes summary data for 1973 and subsequent years.

TOTAL SUSPENDED PARTICULATE DATA COLLECTED AT STATION 72014 FROM 1973 TO 1977

Year	No. of Samples	Geometric Mean (ug/m^3)	Max. 24 Hr. Reading (ug/m^3)	Number of Times Above 24 Hr. Criterion
1973	31	36	80 (July)	Nil
1974	53	32	169 (July)	2
1975	34	42	184 (Sept.)	3
1976	27	21	120 (May)	Nil
1977	14	24	123 (Oct.)	1
Total	159	Max.	184	Total 6

The Provincial criterion for total suspended particulates is 120 ug/m^3 for a 24-hour sample. Since 1973, 159 samples were collected of which only 6 samples exceeded this objective. The Provincial annual criterion for TSP is 60 ug/m^3 (geometric mean). Annual geometric means from 1973 to 1977 have been well below this objective with means ranging from 21 to 42

ug/m^3. In general, higher TSP levels were measured during the months without snow cover on the ground, implicating entrainment of soil and road dust as the major source(s) of particulates.

iii) Elemental Analysis:

In 1976 and 1977, the exposed hi-vol filters were analyzed for zinc, nickel, lead, iron, copper and cadmium. The results of these analyses are presented in Table 3.

Nickel and Cadmium:

The levels of nickel and cadmium were very low with average values approximately 2 orders of magnitude below the Provincial criteria of 2 ug/m^3 for these two metals. Maximum 24-hour values were about 0.02 ug/m^3.

Lead and Copper:

Concentrations of lead in TSP were also quite low and well within the criterion of 5 ug/m^3 for a 24-hour sampling period. Average levels were about 0.1 ug/m^3, with maximum values ranging from 0.3 to 0.5 ug/m^3 in 1976 and 1977 respectively. The levels of copper were much lower than the criterion of 50 ug/m^3. Contamination from the commutator of the hi-vol motor is suspected, such that copper levels measured with hi-vol samplers are not reliable. Nevertheless, the data indicate that the concentration of copper in suspended particulate at the sampling site in Hoyle were very low.

Zinc and Iron:

The concentrations of zinc and iron in TSP, on average, were similar to those of copper. The Province does not have a 24-hour criterion for these elements in suspended particulate. Iron is a natural constituent of soil and road dust. Iron concentrations measured at Hoyle with the hi-vol sampler were typical of background levels resulting from these natural sources.

The levels of zinc in TSP were occasionally elevated, amounting to as much as 10 to 20% of the total dust loading on the filters. In addition, some of the elevated zinc concentrations ($\sim$5 ug/m^3) were obtained during the winter period when snow cover prevents entrainment of soil and road dust. Consequently, these results strongly implicate airborne zinc particulate emissions from the Texasgulf smelter and/or from related activities at the smelter complex (e.g. movement of zinc concentrate by railroad cars, trucks, etc.) as the source of zinc. These findings are in agreement with the results obtained from the mossbag, vegetation and soil sampling programs.

D. Sulphation Rate Measurements

i) Sampling Method:

Sulphation rates are measured by exposing small plastic plates or tubes (candles) coated with lead peroxide (PbO_2) to the atmosphere for 30-day periods. The PbO_2 reacts with

gaseous sulphur dioxide to form lead sulphate ($PbSO_4$). The quantity of sulphate found is analytically determined and reported as milligrams of sulphur trioxide (SO_3) per hundred square centimetres of exposed PbO_2 impregnated material per day (mg SO_3/100 cm^2/day). The method is normally used to detect the presence of sulphur dioxide (SO_2) qualitatively, but other reactive sulphur compounds, such as hydrogen sulphide (H_2S) may also be converted to sulphate. At Hoyle, SO_2 is the major reactive sulphur compound present. The Provincial criterion for sulphation is 0.7 mg SO_3/100 cm^2/day for a 30-day exposure period.

ii) Sulphation Rate Network:

The approximate locations of the sulphation rate monitoring stations are shown in Figures 2 and 3. The survey was operational during the vegetation growing season only. In 1976, sulphation monitors were located at 12 sites throughout the Timmins area (at Hoyle and NE of Hoyle). All stations exposed sulphation candles, except station 72014 where a sulphation plate was used. In 1977, the network was significantly modified in order to monitor sulphation rate values only in the immediate vicinity (< 2.5 km) of the Texasgulf operations. The number of monitoring sites was decreased from 12 to 6, and all sites exposed sulphation plates. The 1978 sulphation survey was identical to the 1977 survey.

iii) Results:

The sulphation rate data for 1976, 1977 and 1978 are presented in Tables 4, 5 and 6 respectively. In 1976, all but 2 sites

measured background sulphation levels. These were sites 72015 and 72014 located 0.8 and 1.6 km ENE of the Texasgulf complex. However, the levels were well below the Provincial criterion. In 1977, the criterion was exceeded twice in July and once in October as indicated in Table 5. Site 72022, located 0.9 km NE of the Texasgulf complex, measured the highest sulphation rates with an average of 0.74 mg SO_3/100 cm^2/day for the season. Stations 72014, 72015 and 72023 measured nearly identical levels, with seasonal means ranging from 0.2 to 0.4 mg SO_3/100 cm^2/day. Sulphation rates at station 72024 were somewhat lower, whereas at station 72016, the levels were at or near the detection limit. In 1978, station 72022 recorded the highest sulphation values with a seasonal mean of 0.67 mg SO_3/100 cm^2/day. The Provincial criterion was marginally exceeded in July and September at that station. The other monitoring stations recorded much lower levels, all well within the criterion.

Consequently, the highest sulphation values in both 1977 and 1978 were recorded at station 72022, located approximately 0.9 km NE of the Texasgulf complex (see Figure 2). The criterion was exceeded for 4 of the 9 samples collected.

E. Mossbag Program

Various studies have shown that the surface ion-exchange capacity of sphagnum moss can be adapted as a tool for monitoring airborne contaminants. The air contaminants are held or trapped on the surface of moss which has been exposed for a period of time in a package or "mossbag" and then the moss can be chemically analysed. Each monitor or mossbag consisted of a thin layer of moss sewn into a pocket of

nylon window screening measuring 8 x 15 cm. The mossbags were attached on wooden holders at a height of 2 metres to wooden utility poles or trees. The holders consisted of a short board with wooden spacers fixed to each and such that the moss did not touch the board (Figure 4). The bag was attached to the spacers by sandwiching the edge of the bag between "Velcro" strips, one of which had been glued to the spacer. Exposed mossbags were replaced monthly with fresh, unexposed mossbags.

In 1976, mossbags were exposed at 12 locations in the vicinity of the zinc refinery. The program was modified and enlarged to 26 monitoring locations in 1977. The locations of the monitoring sites are shown in Figure 5. The monitoring intervals in each year covered the months of June, July, August and September. All mossbags were processed for chemical analysis on a dry weight basis for zinc, copper, lead and arsenic. Unexposed (blank) mossbags were also analysed to determine background concentrations of each of elements in the moss.

Results:

The results of the chemical analysis of the moss are presented in Tables 7 to 11. Some month to month variation in concentrations of the different elements occurred; however, the distribution patterns of the elements over all sampling periods were similar. It is evident from the data that the highest concentrations of the elements were usually measured at the Site M9 located 100 m S of the refinery, and that

concentrations decreased with distance from the refinery. Zinc was the element for which the most highly elevated concentrations were measured. Elevated concentrations occurred to a lesser extent with cadmium, copper and arsenic and to a small extent with lead. Data for the month of July 1977 were selected as being representative of the concentrations of the elements in the moss and this data was used to prepare Figures 6 to 10 which show the distribution of each element in moss exposed around the Texasgulf operation. Elevated zinc, copper and cadmium were found in the moss up to 4 km northeast of the zinc refinery. Lead concentrations were elevated over a much more limited area than zinc, copper or cadmium, mostly within 2 km of the refinery. Arsenic concentrations were elevated within 2 km of the refinery, however, the moss exposed at the two most southwesterly locations (Sites 12 and 30) also contained elevated concentrations of arsenic. These two sites may possibly be affected by dust originating from gold mining operations at these locations.

In summary, the mossbag monitors indicated that elevated concentrations of zinc, copper, cadmium, lead and arsenic existed in air in the vicinity of the refinery and that concentrations of these elements decreased with distance from the refinery. This information corresponds well with other environmental parameters measured in the area and presented in this report.

F. Snow Sampling Program

A snow sampling program was conducted in the vicinity of the

Texasgulf refinery in 1974, 1975 and 1976. The results of the study indicated the presence of a zone of contamination of snow in close proximity to the smelter. Elevated concentrations of zinc, copper, lead and sulphate were involved. The presence of particulates in the snow sample were associated with increased pH values of the snow melt water. A separate report on the results of the snow sampling program has been prepared (4); however, one figure from that report (zinc concentrations in snow, February 1976) has been included in the present report for comparison with other studies (Figure 11).

G. Conclusions

The dustfall data collected at Hoyle (station 72014) indicate that dust levels have generally been within the acceptable limits and are not cause for concern at this time. The impact of particulate emissions from the smelter complex on total dustfall levels at that location appear to have been minimal.

The hi-vol air sampling data implicate natural sources of dust as the major contributor to the levels measured. However, occasionally elevated zinc concentrations in suspended particulate indicate that particulate zinc emissions from either the smelter complex and/or its related activities occur and result in higher than normal zinc concentrations in ambient air.

The Texasgulf smelting operations result in elevated sulphation rates in the immediate vicinity ($\sim$ 1.0 km) of the complex. The sulphation values decreased rapidly

with increasing distance from the smelter such that for distances greater than about 3 km, the levels are at or near background values.

III VEGETATION PLOT PROGRAM

A. Plot Establishment

In conjunction with preoperational environmental studies in the Timmins area, ten permanent vegetation surveillance plots and two control plots were established in 1970 (1). Re-alignment of the program was found to be necessary (5) and some plots were added, while some plots were deleted. The present locations of the plots are shown in Figure 12. The plot numbers and locations with relation to the zinc refinery are as follows:

Plot Number	Location	Year Established
1	0.8 km ENE	1975
2	2.2 km ENE	1973
3	3.2 km NE	1970
4	8.0 km NE	1970
5	16.1 km NE	1970
6	8.0 km E	1970
7	16.1 km E	1970
8 B	1.2 km SW	1976
9	1.6 km SW	1973
10	16.1 km SW	1970
11	32.2 km WSW	1973
12	80.0 km SW	1970

Plot 8B was established in 1976 to replace Plot 8A which had been severely damaged by beaver activity. Plot 12, which had been deleted from the program in 1973, was reactivated as a

control plot in 1978. Site descriptions for the plots have been provided in earlier reports (1,5).

At each plot, 20 representative, healthy trembling aspen trees were selected and tagged. The crown condition, height and diameter of each tree was evaluated and recorded for use in growth studies.

B. Tree Crown Condition and Growth Studies

The crown condition of each tagged tree in the vegetation plots was recorded during each visit in the growing season. The crown condition classification system employed was modified from the system developed by the Canadian Forestry Service for hardwood species in Ontario. A classification gradation from 1A (healthy) to 6B (dead), with several intermediate conditions, allowed for an informative description of the crown condition at the time of evaluation. The presence of air contaminant injury and insect injury was rated on the following arbitrary scale:

Rating	Severity	% Foliage Damaged
1	None to trace	0-5
2	Trace - light	5-10
3	Light	10-20
4	Light - moderate	20-30
5	Moderate	30-40
6	Moderate - severe	40-60
7	Severe	Over 60

The presence of Fomes heart rot and Hypoxylon canker (both fungous diseases) was also recorded. At the end of each growing season, the diameter of each tree was measured.

The only acute air contaminant injury to vegetation, which was observed on any of the study plots, occurred in 1974 at Plot 1 following a process upset condition. No injury was noted at the other plots in 1974 and no injury was recorded at any plot in subsequent years. Fomes heart rot was recorded on a total of 6 living trees in four plots (Table 12). A greater number of living trees were infected by Hypoxylon canker (1978) with 9 plots affected for a total of 29 trees, or 12% of all trees (Table 12).

Insect injury was found to be very common in most plots with many trees moderately to severely injured. Prior to 1975, the main injury was caused by the Large Aspen Tortrix (Choristoneura conflictana Wlk). However, in 1975 there was a considerable increase in the numbers of Aspen Leaf Roller (Pseudexentera oregonana Wlshm.) which caused severe injury in the Timmins-Porcupine area (2). This pest was primarily responsible for injury from 1975 through 1978 (Table 13). This information is also presented in Figure 13. During 1978, the severity of insect injury was observed to decrease over the growing season in 9 of the 12 plots. This decline in the intensity of infestations has been reported by other workers (3) and may represent a collapse of the insect population. The location of the plots in relation to the zinc refinery has no apparent relationship to insect injury severity.

A summary of the data on changes in tree condition is presented in Table 12. The crown condition or viability of trees in August, 1978 was used as the basis for this table. Five trees had died at each of Plots 5 and 6. Lower numbers of trees had died at the other plots. A total of 22 trees had died over all plots and Hypoxylon canker was considered to have caused the deaths of most of the trees which were lost. Nine trees at Plot 10 had declined in crown condition rating. Five trees (in addition to those which had died) declined at Plot 6. Severe defoliation of trees in plots 6 and 10 by insects occurred each year since 1975 and many of the declined trees are not expected to survive for any extended period.

Data on the growth of the tagged trees is summarized in Table 12. Over all plots, growth in 1976 and 1977 was less than in 1975 or 1978. Individual yearly values at different plots were quite variable, therefore, the mean yearly growth of trees over the lifetime of the plot may be more meaningful. The highest rate of growth was recorded at Plot 1 which is nearest to the zinc refinery complex. This information may be somewhat misleading since upon closer examination of the data, smaller trees in the plot (less than 10 cm) grew more rapidly (0.32 cm/year) than did larger trees (over 10 cm) which tended to grow more slowly (0.16 cm/year). Tree growth at Plots 3, 7, 8B, 10 and 12 was less than average. At Plot 3, the trees are located in close proximity to the railroad which may have influenced their growth although good growth was found in certain years. The soil site conditions may be the most important factors at Plots 7 and 10. The soil at Plot 7 is thin and sandy and Plot 10 is very rocky. The soil at the other plots is predominantly on a clay base. Too little data is available for Plots 8B and 12 to draw any conclusions.

From the available data on tree growth, it is not possible to demonstrate that emissions from the refinery have caused a pattern of reduced tree growth in the immediate vicinity of the refinery. Also, the severity of insect injury could not be correlated with a reduced rate of tree growth. Plots with the highest mortality (Plots 5 and 6) (Table 12) had the highest insect severity ratings (Table 13), as well as some of the higher incidences of disease (Table 12). It is apparent then that a number of factors, either alone or in combination, have influenced the rate of growth of the trees. These factors could include:

1: Site-soil factors
2: Insect injury
3: Disease organisms
4: Tree age
5: Soil moisture
6: Refinery emissions.

Additional data is needed in order to assess the impact of these factors in the growth of the tagged trees.

C. Vegetation Injury

Except for the acute SO_2 injury to vegetation which occurred in 1974 (5) following an upset condition in the refinery process, the only observed acute air pollution injury to vegetation was found in close proximity to the refinery following startup of the refining operation. Similar injury occurred each year from 1973 to 1978, primarily to the south and southwest of the zinc refinery. At the time of each surveillance visit in these years, the symptoms and severity of injury

were recorded. The injury symptoms were variable and species - dependent, but marginal and terminal necrosis of foliage tissues were most commonly encountered (Table 14). Frequently the necrosis was preceeded by the development of red or purple anthocyanosis of the tissues. Early loss of the older leaves was sometimes noted with woody species. The severity ratings of injury to eight of the more commonly-noted plant species for various surveillance investigations in the period 1973 to 1978 are shown in Table 15. From the data, it is not possible to conclude that injury severity is either increasing or decreasing with time. However, the data does indicate that injury could occur early in the growing season; that injury could progress during the growing season; and that injury was observed in each year of operation of the zinc refinery.

Injury to the vegetation was most severe in the area approximately 100 m S of the zinc refinery along the Ontario Northland Railroad tracks but was not confined to the immediate vicinity of the tracks. The extent of injury is consistent with the high degree of contamination of this area south of the zinc refinery by various chemical elements, particularly zinc. The contamination by the metals has been demonstrated in snow (8), mossbag studies (this report, Section II E), soils (this report, Section VII) and vegetation (this report, Section IV). The consistency in pattern of zinc distribution and injury to vegetation is easily seen in a comparison of Figures 6, 11, 14 and 26.

The pattern of vegetation injury and contamination would indicate that acid mists and any associated metals emitted

from the cooling towers and cell house of the zinc refinery were probably involved as causal agents of the injury.

The concentrations of chemical elements in vegetation samples collected 100 m south of the zinc refinery are shown in Table 16. The data show some variability in concentrations from year to year within individual species, however, the concentrations of the elements in samples from 100 m south of the refinery are highly elevated in comparison to control samples. All samples from the 100 m south of the refinery contained zinc concentrations in excess of concentrations considered to be excessive while all samples except forage contained copper and cadmium in excessive concentrations. Only dandelion contained lead and arsenic in concentrations considered to be excessive (see Section IV B).

The concentrations of the chemical elements measured in soil samples collected 100 m south of the zinc refinery are presented in Table 17. The data show that zinc concentrations in the upper soil horizons were consistently greater than the concentration considered to be excessive. This also is the case for copper concentrations in the soil with the exception of samples collected in 1974. Soil samples collected only in 1976 or 1977 contained lead, cadmium and arsenic in concentrations considered to be excessive. The higher concentrations of the individual elements were usually measured in the upper horizon samples. There was a strong trend to increasing concentrations of the elements in the soil with time.

IV VEGETATION AND SOIL MONITORING

A. Introduction

As part of the surveillance program conducted in the Timmins area by Ontario Ministry of the Environment, a program of vegetation and soil sampling was initiated in 1970. Originally the sampling was carried out at the ten surveillance and two control vegetation plots established to monitor tree growth and crown condition (see Section III). At each sampling location, foliage samples of trembling aspen, white birch, speckled alder, forage and soil (0-10 cm) were collected. In June, July and August, 1971, this program was expanded to add jack pine and white spruce to the sampled materials. The samples were analyzed for sulphur, silver, arsenic, cadmium, copper, iron, lead and zinc. The sampling was repeated in June, July and August in 1972 and 1973. In 1973 and subsequent years, soil samples were separated into 3 sample depths (0-5, 5-10 and 10-15 cm).

In 1974, the surveillance program was modified and additional plots were added and foliage of trembling aspen, white spruce and forage and soil samples were collected. In 1975 and subsequent years, triplicate samples of only trembling aspen foliage and soil (0-5, 5-10 and 10-15 cm) were collected at each sampling site in July and August. The samples were analyzed for zinc, copper, cadmium, lead and arsenic. Sampling sites not associated with the permanent vegetation plots were also established in 1975 and 1976. The sampling sites used for collection of trembling aspen foliage and soil location of the sites in relation to the zinc plant are as follows:

Site Number	Site Name	Distance & Direction from the Zinc Refinery
1	900 m NE	900 m NE
2	Plot 1	800 m ENE
3	Plot 2	2.2 km ENE
4	Plot 3	3.2 km NE
5	Old Plot 3	3.2 km NE
6	Plot 4	8.0 km NE
7	Plot 5	16.1 km NE
8	Old Plot 1	1.6 km E
9	Plot 6	8.0 km E
10	Plot 7	16.1 km E
11	100 m S	100 m S
12	1000 m S	1000 m S
13	Plot 8	800 m SW
14	Plot 8A	1200 m SW
15	Plot 9	1.6 km SW
16	Plot 10	16.1 km SW
	Control	32.2 km WSW

The sampling locations are shown in Figure 15.

B. Excessive Values

The Ministry of the Environment has conducted numerous vegetation and soil sampling programs throughout the Province of Ontario. Based on experience with these programs as well as on data published in the literature, a set of guidelines has been developed to indicate the concentrations of individual

chemical elements which are considered to be excessive in plant tissue and soil. "Excessive" does not necessarily mean toxic, but is evidence of contamination above average normal levels. These guidelines are useful for many types of vegetation but may not be applied to all vegetation, particularly for those species which accumulate specific elements. The following values are used in this report.

CONCENTRATIONS CONSIDERED EXCESSIVE (ug/g)

Element	Vegetation	Soil
Arsenic	8	25
Cadmium	5	8
Copper	30	100
Lead	50	200
Zinc	250*	400

* Trembling aspen = 400

C. Vegetation Sample Analysis

The concentrations of zinc, copper, cadmium, lead and arsenic in trembling aspen foliage samples are presented in Tables 18 to 22 respectively. Data for samples of any other plant species or any other elements have been summarized in earlier reports (1,5) and will not be considered in the present report.

(i) Zinc:

The concentrations of zinc measured in trembling aspen foliage samples are presented in Table 18. Since

trembling aspen is known to be a natural accumulator of zinc, a value of 400 ug Zn/g tissue was established as the concentration considered to be excessive.

At several locations nearest to the zinc refinery, the foliage samples contained zinc in concentrations considered to be excessive. The highest concentrations of zinc were measured in samples collected 100 m S of the refinery and at Plot 1 (800 m ENE). (Plot 1 was relocated in 1974 after trees at Old Plot 1 were logged in 1973, however foliage samples were still collected at the Old Plot 1 site in 1974 and 1976). At Old Plot 1, zinc concentrations tended to increase from year to year. This increase could be the result of emissions from the zinc refinery and/or windblown concentrate from railroad cars at the siding at Railroad Site 1 (see Section V, Railroad Study). At Old Plot 3, zinc concentrations in aspen foliage showed a tendency to increase each year. These increases were apparently greater than those at sites nearer to the refinery. An investigation into the cause for these increases implicated the railroad which passes near the Old Plot 3 site. By comparison of the analytical results for samples collected at Old Plot 3 with samples collected at Plot 3, which is more distant from the railroad, it is evident that zinc and other elements from passing railroad cars have contaminated the vegetation at Old Plot 3.

At Plots 2, 8 and 9 and the control plot, excessive concentrations of zinc were measured in aspen foliage samples in one or more years. Each of these sampling locations were

established in 1974, therefore no preoperational data is available and it is difficult to assess whether emissions from the zinc refinery were involved in causing the elevated zinc concentrations. At present, it is considered that the emissions from the refinery are having a small influence on vegetation at Plots 2, 8 and 9 but that the elevated zinc concentrations at Control Plot 11 are the result of a natural, slightly elevated zinc content of soil at this location. At all other sampling locations, the zinc content of the aspen foliage is within the normal concentration range for the species or only a limited amount of data is available. The zinc content of samples collected in 1977 is lower than for comparable samples collected in earlier years. This apparent difference is attributed to the fact that samples were collected only in June of 1977 and therefore accumulation of zinc in the foliage throughout the entire growing season was not permitted prior to sample collection.

ii) Copper:

Copper concentrations measured in the samples of trembling aspen foliage are presented in Table 19. Excessive concentrations of copper (over 30 ug/g) were recorded at only three locations. The highest concentrations of copper were measured at the sites nearest to the refinery, at 100 m S and Plot 1. Excessive concentrations of copper were measured in 1976 at Old Plot 3 but this contamination was considered to be related to emissions from the railroad at this location. At other locations, the copper content of trembling aspen foliage was normal and generally similar to those of control samples.

iii) Cadmium:

The concentrations of cadmium in trembling aspen foliage samples are shown in Table 20. Cadmium concentrations of greater than 5 ug/g tissue are considered to be excessive. Elevated concentrations of cadmium were recorded at Plot 1 and 100 m S of the refinery, the two sites nearest to the refinery. The elevated cadmium content of samples collected at Old Plot 3 were attributed to emissions from the railroad. Trembling aspen foliage samples collected at the remaining locations including control locations contain normal amounts of cadmium.

iv) Lead:

No sample of trembling aspen foliage contained lead in concentrations considered to be excessive (50 ug/g) (Table 4). Elevated lead concentrations were measured in samples collected at Plot 1 and 100 m S of the zinc refinery. In general, the samples from other locations contained normal lead concentrations although these values may have been marginally higher than those at the control locations.

v) Arsenic:

Arsenic concentrations measured in the samples of trembling aspen foliage are reported in Table 22. No samples contained arsenic in concentrations considered to be excessive (8 ug/g). Samples collected at Plot 1 and 100 m S of the refinery contained

elevated concentrations of arsenic by comparison with samples from other locations. Samples from the other locations contained normal amounts of arsenic.

D. Soil Sample Analysis

The concentrations of zinc, copper, cadmium, lead and arsenic in soil samples collected in the Timmins area are presented in Tables 23 to 27 respectively. Soil sampling depths for 1970, 1971 and 1972 were 0 to 10 cm but are listed in the tables as 0-5 cm for convenience. In most sample series, the highest concentrations of each respective element were measured in the uppermost soil horizon and decreased with depth. For the sake of simplicity, only the results of surface soils will be discussed here, however, data for all soil depths have been included in the tables.

i) Zinc:

The concentrations of zinc in the soil samples are shown in Table 23. Concentrations of zinc in soil greater than 400 ug/g soil are considered to be excessive. Excessive concentrations of zinc were measured in soil at several locations in close proximity to the zinc refinery. A very high degree of contamination (over 1% zinc) was indicated in soils at 100 m S of the zinc refinery. Zinc content of the soil decreased with distance from the refinery. At Old Plot 3, the elevated zinc content of the soil was attributed to the activities of the railroad in that area. Elevated zinc concentrations at Old Plot 1 could

have resulted from a combination of emissions from the zinc refinery and losses from loaded railroad cars at Railroad Site 1. Variation in soil zinc content was noted from year to year at different locations. This variation made it difficult to demonstrate clearcut trends of concentration changes with time, however, higher values were more frequently encountered in more recent sample periods than during early sample periods. This strongly suggests that zinc contamination of the environment has been occurring since activities related to the zinc refining operation were initiated.

ii) Copper:

Copper concentrations in soil samples collected in the Timmins surveillance area are listed in Table 24. At several locations in the vicinity of the smelter, excessive copper concentrations (over 100 ug/g) were measured in the soil. The highest concentrations were found in samples collected 100 m S of the zinc refinery, Plot 1 and Old Plot 1. The elevated copper content of soil at Old Plot 3 is probably related to emissions from railroad cars passing this site. Within the limitations imposed by year-to-year variation in the soil copper measurements, the copper content of the soils tended to increase, indicating that an input of copper to the soils was continuing.

iii) Cadmium:

The cadmium content of the soil samples is presented in Table 25. Excessive concentrations of cadmium were found in soils

at Plot 1, Old Plot 1 and 100 m S of the zinc refinery, as well as at Old Plot 3 where the railroad influenced the cadmium content of the soil. Cadmium concentrations in soil were higher in recent years than in years before the refinery began operations and generally decreased with distance from zinc refinery.

iv) Lead:

Only one soil sample location indicated excessive concentrations of lead (200 ug/g) (Table 26). This occurred in 1973 at 100 m S, the nearest site to the zinc refinery. Overall, lead concentrations were highest in close proximity to the Texasgulf operation and decreased with distance, but concentrations in soil samples collected nearest to the refinery generally increased with time.

v) Arsenic:

The concentrations of arsenic in the soil samples are summarized in Table 27. The sample collected at 100 m S in 1977 contained excessive concentrations of arsenic (over 25 ug As/g). Excessive concentrations of arsenic were found in samples collected at Plot 8A, however, this site is regarded as an anomolous site with a highly localized contamination by arsenic. In general, higher arsenic concentrations were measured nearest to the refinery and decreased with distance from the refinery, however, samples from sites to the west of the refinery (Plots 8, 9 and 10) had higher concentrations of arsenic than those to the east. The proximity of the westerly plot sites to gold mining activity suggests that airborne arsenic

from the latter activity may have been a factor in the contamination of the soil. This is supported by the slightly elevated arsenic content in the mossbag near Pamour (Site M 30).

V RAILROAD STUDY

Methods

In June 1975, a program was established to determine the importance of concentrate-loaded railroad cars as a source of metal contaminants. In previous years, the Ministry of the Environment had received several complaints concerning wind-blown concentrates from stationary railroad cars on the railroad siding immediately east of the zinc smelter complex. Six sampling sites were selected along the railroad tracks northeast of Hoyle. The locations of the sampling sites are shown in Figure 16. In June 1975, triplicate samples of soil from three depths (0-5, 5-10 and 10-15 cm) were collected at 0,50 and 100 metres from the railroad property line at each of the six selected sites. All samples were collected on the south-east side of the railroad tracks. The program was repeated in June, 1976. All samples were analyzed for zinc, copper, lead, cadmium and arsenic.

The condition of vegetation at Railroad Site 1 was evaluated and recorded in 1975 and 1976. Samples of raspberry and trembling aspen foliage at this location were collected for chemical analysis.

Observations and Results

The injury to various vegetation species observed at Railroad Site 1 in 1975 and 1976 is summarized in Table 28. The injury symptoms generally were similar to those observed on vegetation growing 100 m south of the zinc refinery and injury was confined to plants growing in close proximity to the railroad tracks. The light gray particulate observed on the foliage of plants in 1975 was not present at the time that the 1976 surveillance was conducted.

The concentrations of metals in the vegetation collected at Railroad Site 1 are reported in Table 29. The concentrations of zinc, copper, lead and cadmium are highly elevated in relation to the control samples in all collections. The concentrations of metals increased in raspberry foliage between the June and July collections.

The concentrations of zinc, copper, cadmium, lead and arsenic were found to be greatest near the railroad tracks and decreased with distance from the tracks (Tables 30 to 34). These elements were also found to be present in the highest concentrations in the upper 5 cm of the soil and decreased with depth of the soil sample. There was some variability in results between years with some values higher and other values lower in 1976. The values for comparable samples for each year were usually within the same order of magnitude indicating that the rate of contamination between samplings had not altered significantly in this period. At Sites 1 and 4, the metal content of the soil was extremely elevated, particularly in the case of zinc. At Site 2, the high concentrations of arsenic in the soil

samples taken 50 m from the tracks are considered to be an anomaly.

Selected data for 1976 were plotted to demonstrate the influence of soil sample depth and distance from the railroad tracks by using a 3-dimensional computer plotting program. This information is presented in Figures 17 to 23. Note that the scale for concentration of individual elements is not constant for all sites. These plots clearly show that the surface soils nearest to the tracks are most highly contaminated and that concentrations of the elements decrease with distance from the tracks and with depth of the sample. Figure 23 was included to demonstrate the anomolous arsenic concentrations in soil at 50 m from the tracks at Railroad Site 2. The source of this arsenic is not presently known.

Conclusions

High concentrations of zinc, copper and cadmium were found in surface soils close to the railway. The high concentrations associated with Site 1 and to a lesser extent at Site 2 can be attributed to losses of concentrate from stationary railroad cars at those locations. The highest concentrations of zinc were recorded at Site 4. At this location, there is a gentle curve in the tracks and a small wooded area where passing railroad cars might be subjected to sudden exposure to north-west winds. The winds could cause concentrate material to be blown from the railroad cars. Contamination of snow at this location by zinc and other metals indicates that these metals in the snow (and subsequently in the soil) were airborne and could have originated as wind-blown concentrate from passing railroad cars. By comparison, the concentrations of zinc at Sites 3,

5 and 6 are lower than at the other railroad study sites but are noticeably higher than in comparable soils slightly removed from the railroad.

Contamination of vegetation growing in close proximity to the railroad tracks at Railroad Site 1 was recorded. This location is sufficiently close to the refinery complex to be affected to some degree by emissions from the Texasgulf refining operations, however, there is a decrease in soil zinc content at 50 m from the track. This decrease in zinc is interpreted as soil contamination by zinc in the immediate vicinity of the railroad track. Since the zinc in the soil at this location is readily available to vegetation (see Soil Bioassay Study, Section VI), zinc uptake from the soil as well as wind-blown zinc (grey particulate on vegetation) may have been involved in the contamination of the vegetation.

VI SOIL BIOASSAY STUDY

The environmental monitoring studies conducted in the Timmins area indicated that contamination of soils in close proximity to the zinc refinery and along the Ontario Northland Railroad tracks had occurred. In order to determine whether the metals accumulating in the soil were relatively inert or whether they were able to enter biological components of the ecosystem in the affected area, a bioassay study was initiated. The objective of the study was to determine the availability of zinc and other metals in the contaminated soils by determining the uptake of the metals by plants growing in the soils.

Methods

Bulk soil samples, 0-5 cm in depth, were collected from four locations in the Timmins area (Figure 24). The sampling locations included three contaminated soil: 1) 100 m S of the zinc refinery, 2) Railroad Site 1 and 3) Railroad Site 4. The railroad sites were the same as those described in Section V. Since these contaminated sites were covered by a grass cover, the check site was selected in an uncontaminated grassy area near vegetation Plot 4. The soils were allowed to partially air dry before screening to remove any large pieces of extraneous material and then placed in 1-gallon plastic plant pots. Three replicate pots were prepared for each soil. In addition, a fourth pot of each soil was given a fertilizer addition of 0.51 g 5-20-20 fertilizer, 0.20 g 15-15-15 fertilizer, placed below the seed, plus two applications of 0.20 g of ammonium nitrate, spaced one week apart. Samples of the soil were collected for chemical analysis prior to placing in the pots.

Corn seeds (Cultivar Co-op S-260) were planted in each pot. Corn was used as the test species since various reports have indicated that this species can tolerate some metal contamination of soil and it was necessary to ensure that sufficient plant tissues would be available for chemical analysis. After seedling emergence, the plants were thinned to three uniform plants per plot. The plants were maintained in the greenhouse under natural light conditions (February to April period). The temperature averaged 20°C during the day and 15°C at night. Relative humidity varied between 42% daytime and 55% nightime.

In the course of the experiment, the heights and condition of the corn plants were monitored. The experiment was terminated 56 days after planting. At the time of harvest, the height of each plant was determined and foliage condition evaluated. Chlorosis and necrosis ratings were made on each leaf on a scale of 0 to 5 where 0 represented no injury and 5 represented completely chlorotic or necrotic injury symptoms. The total number of leaves and the number of leaves (mainly older basal leaves) which were completely necrotic were counted. The soil was carefully washed from the roots of the plants and the pooled plants from each pot were separated into roots and shoots for weighing (fresh weight). Dry weights of the samples were determined following oven drying at 105°C for 48 hours. The samples were then processed for chemical analysis.

Results

The concentrations of chemical elements in soil utilized in the bioassay study are presented in Table 35. The results indicated that the soils contained elevated concentrations of zinc, copper, lead, cadmium and arsenic in comparison with the check soil. Soils from the railroad study sites contained higher concentrations of these elements than did soil from 100 m south of the refinery and Railroad Site 4 contained higher quantities of metals than Railroad Site 1.

The yield and condition data for plants grown in the bioassay study are summarized in Table 36. Yield parameters (fresh and dry weight, height, leaves per plant) were generally consistent within treatments. Plants grown in soil from

100 m south and Railroad Site 1 were heavier, taller and had more leaves than did plants in the other treatments. The smallest plants were grown in soil from Railroad Site 4. Greater foliage mortality and higher chlorosis and necrosis of leaf tissues were recorded on these smaller plants. The relative yields among the treatments do not correspond to the degree of contamination of the soil by the various metals. The yields, however, do parallel the magnesium and potassium content of the soil suggesting that these elements may be limiting factors in the growth of the corn plants in some treatments.

The addition of fertilizer produced larger plants in all treatments by comparison with plants which received no additional fertilizer. Plants grown in soil from Railroad Site 1 were the largest among both fertilized and fertilized plants, while corn plants growing in soil from Railroad Site 4 were smallest, under both fertilizer treatments. The response of check-soil treatment plants to fertilizer resulted in plants larger than plants growing in fertilized soil from 100 m south of the refinery. The response of the plants to fertilizer with regard to foliage condition was not conclusive, but plants growing in soil from Railroad Site 4 had the highest ratings of chlorosis and necrosis.

Necrosis of the foliage was first noted in the terminal portions of the corn leaf and progressed towards the base of the leaf. The symptoms were not typical of those of commonly known nutrient deficiencies (6,7) although some potassium deficiency, as noted above, might have been involved. The necrotic tissue as it developed was preceeded by a broad band of red antrhocyanotic tissue. This symptom was similar

to that noted in vegetation injury observed in the field in close proximity to the zinc refinery (see Section III, C).

The concentrations of chemical elements measured in tissues of the corn plants are presented in Table 37. In the majority of cases, root samples contained higher concentrations of all elements than did the foliage of corresponding samples. Lead and arsenic concentrations in roots and foliage were similar in plants from all treatments indicating that these elements were not being taken up by the plant from the contaminated soils. Copper concentrations within the roots of the corn plants reflected the contamination of soil by this element, however, the copper was apparently not translocated from the roots into the foliage. Cadmium was taken up by plants growing in contaminated soil and a portion was translocated into the foliage. The zinc concentrations in both foliage and roots reflected the contamination of soil by zinc. The highest concentrations of zinc were measured in plants growing in soil from Railroad Site 1 (smallest plants with greatest injury). Plants growing in soil from both railroad sites contained zinc in concentrations considered to be excessive. It was not possible to conclude that the application of fertilizer influenced the uptake of the contaminants since only a single replicate per treatment was used for the fertilized plants and differences between fertilized and non-fertilized treatments were either small or variable.

Conclusions

Corn plants grown in the contaminated soils contained elevated concentrations of zinc in the roots and foliage indicating that

the zinc present in the soil was readily available to vegetation. By comparison, lead and arsenic were not taken up by plant roots or translocated to the foliage. Copper and cadmium were taken up by the plant roots and only weakly translocated into the foliage. Based on this information, the availability of each of the elements to vegetation can be ranked as follows Zn > Cd > Cu > Pb = As.

Injury symptoms developed on the foliage were similar to those observed in the field (anthocyanosis developing prior to necrosis of terminal and marginal tissues). Yield parameters indicated that growth of the plants, only in treatment Railroad Site 4, might have been adversely affected by metal contaminants in the soil. The response of the plants in all treatments to fertilizer indicates that the unfertilized plants were also subject to nutrient deficiency stress but the importance of this stress under natural conditions in combination with metal contamination could not be determined from the present test results.

VII SYMAP PROGRAM

The various programs conducted in the vicinity of the Texasgulf refinery indicated that environmental contamination by several elements was occurring in close proximity to the refinery complex. From the data obtained in these programs, it was not possible to assess the extent of the contamination in any detail. It was therefore decided that a more intensive sampling program was needed in order to understand the pattern and degree of contamination. The intensive sampling

program would also provide a large data base upon which changes in the degree of contamination due to continued operation or expansion of the refinery, might be assessed.

Method

A total of 56 sampling locations were selected in the vicinity of the refinery, based on accessibility of the sites, land use and distribution of sample sites around the complex. Sampling sites in close proximity to the zinc refinery were spaced at 100 m intervals while more distant sites were spaced 200, 500 or more metres apart. The distribution of the sample sites is indicated in Figure 25.

Triplicate soil samples from three depths (0-5, 5-10 and 10-15 cm) were collected at each site in June, 1977. The samples were prepared for chemical analysis for zinc, copper, cadmium, lead and arsenic content.

The analytical results for the samples were coded and subjected to a computer analysis. The computer analysis program (SYMAP) developed at Harvard University displayed the coded information on the distribution of various parameters as contour maps. Intervals between contours were selected for each of the elements tested as indicated in the following table:

Contour Interval	Element			
	Zn	Cu	Cd	As
1	<100	<50	<5	<5
2	100-500	50-100	5-10	5-10
3	500-1000	100-200	10-20	10-20
4	1000-2000	200-500	20-30	20-30
5	2000-5000	>500	30-40	>30
6	>5000		>40	

Results

The figures prepared for the distribution of each element in the upper 5 cm of soil have been simplified in Figures 26 to 29. SYMAP computer output sheets for other soil sampling depths were also prepared and these indicate similar distribution patterns for the respective elements but also reflect the decrease in concentration of the element with increasing depth of the soil. They were not included in this report for the sake of brevity.

Distribution of Zinc

The distribution of zinc in the soil (0-5 cm) is shown in Figure 26. The highest concentrations of zinc (>5000 ug/g) were found in samples taken immediately to the south of the zinc refinery. High concentrations of zinc were also measured in a band running north east from the zinc refinery for a distance of about 500 m and in the vicinity of Railroad Site 1 (see Railroad Study - Section V). Concentrations of zinc declined with distance from the two centres of elevated zinc noted above.

Distribution of Copper

Copper concentrations in the soil (0-5 cm) are shown in Figure 27. The highest copper concentrations (>500 ug/g) were found in samples collected south west of the zinc refinery and in the vicinity of Railroad Site 1. The concentrations of copper in the samples decreased with increasing distance from these two centres of elevated

copper concentration.

Distribution of Cadmium

The distribution of concentrations of cadmium measured in the soil samples is shown in Figure 28. The highest concentrations of cadmium were found immediately south of the refinery with values greater than 40 ug Cd/g soil reported. Two small centres of elevated cadmium values were found northeast of the refinery and at Railroad Site 1. Cadmium concentrations decreased with distance from the refinery.

Distribution of Arsenic

The arsenic concentration distribution pattern in soil is shown in Figure 29. Elevated concentrations of arsenic were noted at several locations including the area immediately south of the Texasgulf refinery suggesting that the refinery was associated with contamination of the soil by arsenic and other elements noted above at this location. Elevated arsenic values were measured at a site approximately 100 m east of the junction of Highway 101 and Highway 610. Railroad Site 2 is located a short distance west of the junction of the highways and at this location, elevated concentrations of arsenic were also found 50 m from the railroad (not indicated in Figure 29). Elevated arsenic concentrations were also found 1200 m southwest of the refinery complex at Plot 8A (see Section IV - Vegetation and Soil Monitoring) but high arsenic values reported at this site were considered to be anomolous. Arsenic concentrations in soil at Plots 9 and 10 (see Section IV), were slightly elevated above

background values. Airborne arsenic measured by mossbag monitors (Section II E) at Sites M12 and M30 in the general area of Plot 9 were attributed to possible emissions from gold mining operations in that area. Until additional studies are undertaken, the source of arsenic found in various limited areas cannot be determined.

Conclusions

Due to limitations of the output format at the SYMAP program, it is not possible to exactly position the sampling locations on the prepared figures but they are shown at the nearest possible position allowed by the printed characters. Similarly, the isopleths drawn between the various concentrations intervals are not smooth. The limited number of samples available in the area to the north west (tailings area) and to the south east limits the accuracy of data generated on the figures in these areas. Since the number of sampling points was concentrated the immediate vicinity of the refinery, the accuracy of the prepared figures is much greater in these areas and probably reflects fairly, the situation which exists around the refinery. The SYMAP technique is therefore considered to be a useful tool in demonstrating the extent and degree of contamination of soils by various elements in the vicinity of refinery. The prepared figures will be useful as a basis for monitoring changes in the degree of contamination of the soils in the area due to any future emissions from the refinery complex.

VIII NEW STUDIES

The various studies conducted in the vicinity of the Texasgulf refinery indicated that contamination of the environment in the immediate vicinity of the operation by zinc and other elements was occurring. Although widespread destruction of the dominant types of vegetation in the affected area could not be demonstrated, it was felt that continued input of the contaminants into the environment would have a negative effect on the biological components in the environment. This negative effect could be rather subtle and take some time to become obvious. A series of new investigations was initiated as a means of monitoring these subtle effects.

The largest part of the emissions from the refinery operation would normally be expected to be deposited on the soil or on vegetation. At the end of the growing season, contaminants in or on the foliage would reach the soil with falling leaves, etc., and enter the process of elemental cycling in the environment. Toxic contaminants reaching the soil could possibly affect agents involved in the natural cycling processes, therefore, it was decided to monitor any changes in these agents. These agents include soil microarthropods (mites, small insects, centipedes, etc.) soil bacteria, fungi, actinonycetes, earthworms and many other types of organisms. The studies were designed to monitor the populations (measure the numbers) of these organisms and to determine their collective rate of activity (measure the rate of decomposition of leaf material on the soil surface)

at several locations in the vicinity of the refinery. The studies were initiated in the fall of 1977. Since the studies have not been completed, the results were not available for inclusion in this report but will be included in any future reports.

IX CONCLUSIONS

Air quality monitoring indicated that dustfall and high volume air sampling measurements were generally within acceptable limits at a site 1.6 km ENE of the zinc refinery. Snow sampling and mossbag monitorings programs showed that concentrations of several elements in air (especially zinc) were elevated in close proximity to the refinery. These elements were found to contaminate foliage of vegetation and to accumulate to high concentrations in the soil near the zinc refinery. Injury to vegetation was noted in the most highly contaminated zone. Due to variation in growth associated with various other environmental factors, it was not possible to demonstrate that growth of aspen trees was reduced in the vicinity of the Texasgulf complex. Contamination of soil in the vicinity of the Ontario Northland Railroad tracks was demonstrated and this problem must be considered when environmental parameters are being monitored in the vicinity of the Texasgulf operation.

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XI BIBLIOGRAPHY

1. Balsillie, D. and P.C. McGovern, 1972. Background report for environmental studies in the Timmins area. Air Quality Branch, Ontario Ministry of the Environment, Sudbury, Ontario. 8 pp.

2. MacLeod, L.S., H. Evans and J. Hook, 1976. Forest insect and disease surveys in the Northern Region of Ontario, 1975. Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario. 19 pp.

3. McDowall, L.L. and G.M. Howse, 1978. Survey Bulletin. Forest Insect and disease conditions in Ontario, Summer, 1978. Great Lakes Forest Research Centre, Canadian Forestry Service, Sault Ste. Marie, Ontario. 12 pp.

4. McIlveen, W.D. and D. Balsillie, 1979. Snow Sampling studies in the vicinity of the Texasgulf Smelter, Timmins, Ontario. Ontario Ministry of the Environment, Northeast Region. (In preparation).

5. McIlveen, W.D. and R.R. Potvin, 1976. Air Quality Assessment Studies in the Timmins Area (1975). Ontario Ministry of the Environment, Northeast Region. 60 pp.

6. Sprague, H.B., 1964. Hunger signs in crops, Third Edition. D. McKay Company, New York, N.Y. 461 pp.

7. Anonymous, 1973. A compendium of corn diseases. Amercian Phytopathological Society, St. Paul, Minnesota. 64 pp.

8. Anonymous, 1978. Texasgulf Annual Report 1977. Texasgulf Inc. New Yor, N.Y.

XII APPENDIX

TABLE 1

TOTAL DUSTFALL LEVELS (g/m^2/30 days) MEASURED AT STATION 72014 IN 1976 AND 1977

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Mean
1976	1.1	0.7	2.8	6.0	3.2	4.2	4.2	5.3	4.9	-	-	-	3.6
1977	-	0.7	3.1	2.8	-	5.8	-	5.3	6.5	3.8	2.0	-	3.8

Note: - indicates data is missing or is invalid.

The Ontario criterion for total dustfall is 7.0 g/m^2/30d for a 30-day period, and 4.0 g/m^2/30d for a 12 month period.

TABLE 2

ELEMENTAL ANALYSIS OF DUSTFALL SAMPLES COLLECTED AT STATION 72014 DURING 1976 AND 1977

Year	Element	No. of Samples	Maximum Value ($g/m^2/30d$)	Mean ($g/m^2/30d$)
1976	As	8	0.0001	B.D.L.
	Cu	9	0.004	0.003
	Fe	9	0.120	0.054
	Pb**	9	0.109	0.034
	Ni	9	0.001	B.D.L.
	Zn	9	0.07	0.05
1977	Cu	4	0.003	0.002
	Pb**	4	0.003	0.002
	Zn	4	0.07	0.04

* B.D.L. - Below detection limit of analytical method.
** Ontario criterion for lead in dustfall is 0.1 $g/m^2/30d$

TABLE 3

HEAVY METAL ANALYSIS OF HIGH VOLUME AIR FILTERS

EXPOSED AT HOYLE (STATION 72014) IN 1976 AND 1977

Element	No. of Samples Analyzed		Max. 24-Hr. Value (ug/m^3)		Geometric Mean (ug/m^3)		Provincial Criterion
	1976	1977	1976	1977	1976	1977	For 24-Hr. (ug/m^3)
Zn	24	10	5.9	4.1	0.4	0.3	No criterion
Ni	24	10	0.025	0.017	0.001	0.002	2
Pb	24	10	0.3	0.5	0.1	0.1	5
Fe	24	10	3.7	3.2	0.5	0.4	No criterion
Cu	24	10	2.1	1.2	0.4	0.4	50
Cd	24	10	0.026	0.023	0.002	0.005	2

TABLE 4

SULPHATION RATES (mg SO_3/100 cm^2/day) DETERMINED

WITH LEAD PEROXIDE CANDLES EXPOSED IN THE TIMMINS AREA IN 1976

Station No.	Distance and Direction From Texasgulf (Hoyle)	May	June	July	August	September	Mean
72015	0.8 km ENE	0.26	0.29	0.18	0.18	0.30	0.26
72016	2.2 km ENE	0.07	0.04	0.05	0.05	0.07	0.06
72002	3.2 km NE	0.05	0.03	0.06	0.05	0.04	0.05
72003	8.0 km NE	0.05	0.03	0.06	0.03	0.02	0.04
72004	16.1 km NE	0.05	0.03	0.02	0.06	0.05	0.04
72006	8.0 km E	0.05	0.02	0.04	0.05	0.02	0.04
72007	16.1 km E	0.05	0.02	0.02	0.05	0.02	0.03
72024	1.0 km SW	0.13	0.13	0.02	0.09	0.04	0.08
72025	1.6 km SW	0.07	0.04	0.02	-	0.01	0.04
72009	16.1 km SW	0.05	0.02	0.06	0.03	0.02	0.04
72027	32.2 km WSW	0.06	0.02	0.07	0.03	0.01	0.04
72014	1.6 km ENE*	-	0.34	0.18	0.45	-	0.32

Note: * Sulphation plate

Ontario criterion = 0.7 mg SO_3/100 cm^2/day

- indicates data is missing or is invalid

TABLE 5

SULPHATION RATES (mg SO_3/100 cm^2/day) DETERMINED

WITH LEAD PEROXIDE PLATES EXPOSED IN THE TIMMINS AREA IN 1977

Station No.	Distance and Direction From Texasgulf (Hoyle)	May	June	July	August	September	October	Mean
72014	1.6 km ENE	0.29	0.13	0.37	0.17	0.18	-	0.23
72015	0.8 km ENE	-	0.24	0.95	0.10	0.29	0.36	0.39
72016	2.2 km ENE	-	B.D.L.	B.D.L.	-	0.07	B.D.L.	-
72022	0.9 km NE	-	0.52	1.62	0.49	0.25	0.81	0.74
72023	0.6 km SE	-	0.31	0.57	0.08	0.23	-	0.29
72024	1.0 km SW	-	0.16	B.D.L.	-	0.12	0.07	0.12

Note: - indicates data is missing or is invalid

B.D.L.: below the detectable limit

Underlined values exceeded the Ontario criterion of 0.7 mg SO_3/100 cm^2/day

TABLE 6

SULPHATION RATES (mg SO_3/100 cm^2/day) DETERMINED

WITH LEAD PEROXIDE PLATES EXPOSED IN THE TIMMINS AREA IN 1978

Station No.	Distance and Direction From Texasgulf (Hoyle)	June	July	August	September	Mean
72014	1.6 km ENE	0.16	-	0.14	0.21	0.17
72015	0.8 km ENE	-	-	0.03	0.29	-
72016	2.2 km ENE	0.36	0.02	0.01	0.03	0.10
72022	0.9 km NE	0.39	0.87	0.61	0.82	0.67
72023	0.6 km SE	0.20	0.29	0.07	0.23	0.19
72024	1.0 km SW	0.20	0.06	0.02	0.08	0.09

Note: - indicates data is missing or is invalid

Underlined values exceeded the Ontario criterion of 0.7 mg SO_3/100 cm^2/day

TABLE 7

CONCENTRATIONS OF ZINC (ug/g) IN MOSS IN MOSSBAGS EXPOSED IN THE TIMMINS AREA IN 1976 AND 1977

Site	1976				1977			
	June	July	August	September	June	July	August	September
M1	620	940	540	481	390	2200	500	350
M2	46	131	214	198	180	400	144	194
M3	350	770	468	500	300	760	500	270
M4	112	370	334	384	278	440	360	270
M5	84	160	77	107	-	-	-	-
M6	46	61	43	-	74	74	60	75
M7	52	68	-	-	-	-	-	-
M8	25	135	29	32	66	64	60	60
M9	2030	2370	550	560	3800	2300	1280	1500
M10	135	260	205	185	-	-	79	216
M11	188	410	69	61	146	114	94	120
M12	33	46	28	26	84	64	60	62
M14					92	134	110	-
M15					78	192	110	70
M16					156	106	80	70
M17					114	220	252	146
M18					64	68	68	82
M19					76	162	78	79
M20					56	100	66	58
M21					66	-	140	60
M23					188	-	930	360
M24					380	480	206	280
M27					150	72	70	70
M28					234	124	-	83
M29					222	94	64	112
M30					116	72	62	70
M31					-	220	176	108
M32					76	70	134	95
Blank			15		51	54	67	52
Days Exposed	21	34	36	28	33	30	28	32

TABLE 8

CONCENTRATIONS OF COPPER (ug/g) IN MOSS IN MOSSBAGS EXPOSED IN THE TIMMINS AREA IN 1976 AND 1977

Site	1976				1977			
	June	July	August	September	June	July	August	September
M1	62	75	110	50	53	60	134	49
M2	6	8	16	11	16	22	18	23
M3	35	74	57	33	47	73	144	95
M4	12	11	24	10	24	32	88	60
M5	7	6	10	4	-	-	-	-
M6	8	6	3	-	9	8	9	8
M7	6	3	-	-	-	-	-	-
M8	6	6	9	10	9	8	8	9
M9	96	118	112	194	420	92	93	122
M10	8	10	10	8	-	-	9	18
M11	12	15	18	8	11	8	9	12
M12	4	4	6	3	12	9	9	9
M14					12	10	13	-
M15					12	13	20	12
M16					66	41	22	22
M17					20	27	43	38
M18					10	8	11	11
M19					11	10	17	10
M20					9	9	12	9
M21					11	-	20	9
M23					43	-	380	54
M24					68	94	21	28
M27					12	8	10	9
M28					24	11	-	9
M29					22	16	13	16
M30					11	8	8	8
M31					-	20	27	16
M32					10	11	17	11
Blank			2		9	8	8	8
Days Exposed	21	34	36	28	33	30	28	32

TABLE 9

CONCENTRATIONS OF CADMIUM (ug/g) IN MOSS IN MOSSBAGS EXPOSED IN THE TIMMINS AREA IN 1976 AND 1977

	1976				1977			
Site	June	July	August	September	June	July	August	September
M1	4.9	10.3	16.5	5.1	3.8	21.4	7.4	6.4
M2	.5	.7	1.7	1.0	2.0	3.0	1.8	2.4
M3	3.6	7.0	5.5	5.0	4.0	8.4	5.8	5.2
M4	.8	1.1	2.1	1.8	2.0	4.8	4.0	3.0
M5	.4	.7	1.0	.6	-	-	-	-
M6	.4	.5	1.1	-	1.4	1.6	1.4	2.0
M7	.5	.3	-	-	-	-	-	-
M8	.5	1.0	1.2	.8	1.6	1.8	1.2	1.6
M9	11.4	35.4	25.0	41.4	39.4	63.2	9.6	18.8
M10	.8	1.2	1.6	1.7	-	-	1.4	2.0
M11	.8	3.2	1.2	1.7	2.0	1.8	1.6	1.9
M12	.5	.4	1.1	1.0	1.8	1.4	1.4	1.7
M14					1.8	1.8	1.7	-
M15					1.4	2.4	1.6	1.6
M16					2.0	1.8	1.4	1.6
M17					3.8	3.4	2.8	2.2
M18					1.4	1.8	1.6	1.5
M19					1.4	2.0	1.6	1.6
M20					1.4	2.0	1.6	1.4
M21					1.8		2.2	1.5
M23					2.0	-	17.1	3.6
M24					4.6	10.4	2.2	4.8
M27					2.0	1.6	1.4	1.3
M28					2.6	2.0	-	1.5
M29					4.4	1.8	1.8	2.9
M30					1.8	2.6	1.4	1.3
M31					-	3.4	2.0	1.8
M32					1.6	2.6	2.0	1.4
Blank			.5		1.4	1.4	1.3	1.3
Days Exposed	21	34	36	28	33	30	28	32

TABLE 10

CONCENTRATIONS OF LEAD (ug/g) IN MOSS IN MOSSBAGS EXPOSED IN THE TIMMINS AREA IN 1977

Site	June	July	August	September
M1	46	74	64	40
M2	30	34	29	32
M3	-	52	54	40
M4	30	44	52	42
M6	30	30	30	25
M8	34	30	30	30
M9	186	90	50	49
M10	-	-	26	40
M11	31	26	32	32
M12	40	34	30	32
M14	30	32	33	-
M15	20	34	34	30
M16	46	36	34	34
M17	34	50	46	40
M18	30	34	34	34
M19	34	38	34	34
M20	32	33	34	32
M21	40	-	36	30
M23	38	-	109	36
M24	60	58	44	40
M27	32	33	32	30
M28	37	34	-	28
M29	36	30	34	28
M30	36	34	34	28
M31	-	32	34	26
M32	34	34	34	26
Blank	32	31	28	30
Days Exposed	33	30	28	32

TABLE 11

CONCENTRATIONS OF ARSENIC (ug/g) IN MOSS IN MOSSBAGS EXPOSED IN THE TIMMINS AREA IN 1976 AND 1977

	1976				1977			
Site	June	July	August	September	June	July	August	September
M1	4.9	3.2	4.4	2.6	2.2	3.2	1.8	1.5
M2	1.2	.9	1.0	1.0	.8	.9	.6	1.1
M3	4.4	2.2	2.4	2.6	3.0	2.2	1.7	1.4
M4	1.8	1.1	1.1	1.0	1.3	1.3	1.0	.8
M5	.7	.9	.9	.7	-	-	-	-
M6	.9	.7	.9	-	.4	.5	.5	.6
M7	.6	.6	-	-	-	-	-	-
M8	.5	.6	.6	.6	.4	.4	.5	.7
M9	12.0	11.0	5.2	12.6	17.2	15.8	.9	8.4
M10	1.0	.9	.6	.9	-	-	.6	1.2
M11	.9	1.1	.8	1.2	.5	.6	.6	.6
M12	1.3	2.5	1.2	1.2	7.6	4.1	1.4	2.4
M14					.4	.5	.5	-
M15					.7	.6	.6	.6
M16					.9	.8	.5	.6
M17					.9	.6	.9	.7
M18					.6	.9	.5	.5
M19					.6	.5	.5	.6
M20					.5	.6	.5	.6
M21					.5	-	.7	.6
M23					1.0	-	3.0	1.0
M24					3.4	2.3	.7	2.3
M27					.7	.7	.5	.6
M28					1.0	.7	-	1.2
M29					.5	.6	.5	.6
M30					3.2	1.8	.9	.7
M31					-	.5	.6	.5
M32					.7	.6	.5	.6
Blank			.6		.5	.6	.5	.5
Days Exposed	21	34	36	28	33	30	28	32

TABLE 12

SUMMARY OF THE CONDITION OF TREMBLING ASPEN TREES IN SURVEILLANCE PLOTS IN THE TIMMINS AREA*

PARAMETER	Plot Number 1	2	3	4	5	6	7	8B	9	10	11	12	Total or Mean
Year Established	1975	1973	1970	1970	1970	1970	1970	1976	1973	1970	1973	1970	
Total Dead	3	0	3	2	5	5	1	0	0	0	1	2	29
Total Declined**	4	0	1	3	6	10	3	1	0	9	1	3	41
Fomes Heart Rot	0	0	0	1	2	0	0	0	2	0	1	0	6
Hypoxylon Canker	1	0	0	3	7	3	2	1	4	6	0	2	29
Growth*** 1975 (cm)	-	.31	.34	.42	.21	.05	.10	-	.16	.14	.18	-	.21
1976 (cm)	.27	.21	.16	.21	.08	.16	.13	-	.22	.11	.32	-	.19
1977 (cm)	.50	.15	.08	.02	.02	.32	.07	.02	.06	.10	.20	-	.18
1978 (cm)	.30	.27	.39	.18	.29	.34	.13	.16	.24	.10	.37	-	.25
Mean Annual Growth Rate (cm/yr)	.37	.25	.18	.24	.22	.29	.17	.09	.27	.14	.31	.19	.23
Mean Diameter (cm) 1978	11.5	12.1	16.0	14.5	17.1	15.7	11.1	15.3	21.4	9.6	19.0	19.1	-

* Data Based on 20 trees per plot

** Total Declined includes Dead Trees

*** Growth Rate Equals Increase in D.B.H. per year

TABLE 13

MONTHLY INSECT INJURY SEVERITY RATINGS

MEASURED IN TIMMINS ASPEN PLOTS 1975 - 1978**

	1975			1976			1977			1978			
Plot	J*	J*	A*	J	J	A	J	J	A	J	J	A	Mean Severity
1	-	3.1	4.5	4.5	4.4	3.8	4.3	4.7	4.8	5.9	5.8	5.6	4.67
2	1.0	2.9	3.5	3.7	3.7	4.2	4.3	5.0	4.9	6.1	5.1	4.5	4.08
3	1.0	3.0	4.7	3.7	4.7	5.6	5.5	5.9	6.2	6.3	6.4	6.4	4.95
4	1.0	2.8	4.4	4.6	5.1	6.2	3.9	4.4	5.1	5.6	5.6	5.3	4.50
5	2.8	4.1	5.4	5.8	5.8	6.3	6.5	6.5	6.5	6.6	6.8	6.9	5.83
6	1.0	2.7	4.2	5.5	5.5	6.5	5.8	5.8	6.2	6.8	6.6	6.3	5.24
7	1.0	3.3	4.4	4.2	4.8	6.2	4.7	5.1	4.9	5.4	4.4	4.9	4.44
8	-	-	-	-	-	-	3.7	3.9	4.0	7.0	5.4	5.1	4.85
9	1.0	3.2	5.7	3.6	4.3	4.6	4.2	4.2	4.5	5.7	4.3	3.9	4.10
10	1.0	1.2	5.3	3.1	3.9	5.3	5.0	5.6	5.6	6.2	6.0	6.0	4.52
11	1.0	1.4	3.3	1.0	1.9	2.3	2.8	3.2	4.5	5.1	4.6	4.0	2.93
12	-	-	-	-	-	-	-	-	-	3.0	3.2	3.2	3.13

* J J A - June, July, August, respectively

** Values are mean of ratings given to individual trees as outlined in the text

TABLE 14

PREDOMINANT SYMPTOMS OF INJURY OBSERVED TO VARIOUS VEGETATION SPECIES GROWING IN CLOSE PROXIMITY TO THE TEXASGULF REFINERY

Species	Symptoms
Dandelion	Terminal anthocyanosis, intercostal necrosis, white spotting
Fireweed	Marginal necrosis and necrotic spotting
Vetch	Terminal and intercostal necrosis
Large-leaved Aster	Marginal necrosis, white spotting
Yellow Avens	Marginal necrosis, intercostal necrotic spotting
Daisy	Marginal necrosis
Buttercup	Terminal chlorosis, necrosis and anthocyanosis becoming necrotic
Sowthistle	Marginal anthocyanosis
Bindweed	Marginal anthocyanosis becoming necrotic
Evening Primrose	Marginal necrosis, large necrotic spots
Golden Rod	Terminal and intercostal necrosis
Clintonia	Terminal necrosis
Pearly Everlasting	Terminal necrosis
Botrychium Fern	Terminal necrosis
Horsetail	Terminal necrosis
Timothy	Terminal necrosis and chlorosis
Twitch grass	Terminal necrosis
Currant	Marginal anthocyanosis becoming necrotic
Gooseberry	Marginal anthocyanosis
Raspberry	Marginal necrosis, white spotting
Dewberry	Marginal Anthocyanosis
Wild Rose	Marginal Anthocyanosis and necrosis, defoliation
Elderberry	Black marginal necrosis, epinasty, defoliation
Honeysuckle	Intercostal necrosis
Prairie Willow	Intercostal necrosis at base of leaves, defoliation
Alder	Intercostal and marginal necrosis
Red Ozier Dogwood	Intercostal necrotic spotting
Trembling Aspen	Dark brown marginal and intercostal necrosis

TABLE 15

SEVERITY RATINGS OF INJURY TO FOLIAGE OF SELECTED PLANT SPECIES GROWING IN CLOSE PROXIMITY TO THE TEXASGULF ZINC RFINERY 1973 - 1978

	1973		1974			1975			1976			1977		1978
Species	June 7	Aug 16	June 12	July 17	Aug 8	June 26	July 22	Aug 27	May 26	July 19	Aug 23	May 25	June 29	June 8
Currant	-	Light	-	-	-	Light	Trace	-	Light	Light	-	None	Moderate	Light-Moderate
Dandelion	-	-	Light	Light	-	Light	Severe	Light	Light	Light	Moderate	None	Light-Moderate	Moderate
Elderberry	Light-Moderate	Moderate	-	Trace	-	Light-Moderate	Light-Moderate	Light	Light	Light	Severe	None	-	-
Fireweed	-	Severe	-	Moderate	Light	Moderate	Moderate	-	Light	Moderate-Severe	Severe	None	Light-Moderate	-
Grass spp.	Trace	Light	-	-	-	-	-	Severe	Light	Light	-	None	Moderate	-
Honeysuckle	-	-	-	-	-	-	Severe	Severe	Light	-	-	None	Severe	-
Raspberry	Light-Moderate	Moderate	Trace	Moderate	-	Light-Moderate	Light	Light	-	Light	Light	None	-	-
Vetch	-	-	-	-	-	-	None	Severe	Light-Severe	-	-	None	Light-Moderate	Moderate

TABLE 16

CONCENTRATIONS OF CHEMICAL ELEMENTS IN VEGETATION SAMPLES COLLECTED 100 m SOUTH OF THE TEXASGULF ZINC REFINERY 1973 - 1977

		ELEMENT				
Year	Species	Zn	Cu	Pb	Cd	As
1973	Raspberry	3680	125	33	15	-
	Control	122	6	21	1	-
1973	Balsam Fir	3550	194	149	31	-
	Control	3	4	18	<1	-
1973	Fireweed	2590	156	42	20	-
1974	Fireweed	1050	42	22	3	-
1976	Control	2340	63	43	21	4.1
1973	Elderberry	2450	62	36	7	-
	Control	71	6	24	1	-
1974	Dandelion	5650	110	66	13	-
1976	Dandelion	5067	166	81	33	51.0
	Control	89	17	8	<1	0.6
1974	Trembling Aspen	1300	35	20	5	-
1975	Trembling Aspen	1672	76	(22)*	(6)*	-
1976	Trembling Aspen	2415	64	41	18	6.0
1977	Trembling Aspen	1266	183	43	15	5.6
	Control	387	10	8	1	0.3
Excessive Values		250	30	50	5	8
(Trembling Aspen - 400)						

* Values reported for 1975, 1976, and 1977 are means of triplicate samples

TABLE 17

CONCENTRATIONS OF CHEMICAL ELEMENTS IN SOIL SAMPLES COLLECTED 100 m SOUTH OF THE TEXASGULF ZINC REFINERY 1973 - 1977*

Year	Depth (cm)	ELEMENT Zn	Cu	Pb	Cd	As
1973	0-5	1290	128	28	8	-
	5-10	220	28	18	3	-
	10-15	135	18	20	<3	-
1974	0-5	380	45	48	6	-
	5-10	610	58	53	6	-
	10-15	205	28	35	4	-
1975	0-5	1400	118	56	6	-
	5-10	213	38	34	2	-
	10-15	131	45	34	3	-
1976**	0-5	6700	428	188	30	17
	5-10	848	75	42	4	3
	10-15	708	70	45	4	4
1977	0-5	17900	475	230	41	28
	5-10	673	58	45	3	5
	10-15	154	36	29	3	4
Excessive Value		400	100	200	8	25

* Values reported are for single samples collected in 1973 and 1974 and triplicate samples in 1975, 1976, and 1977

** Values reported for 1976 are means of two monthly samples collected in triplicate

TABLE 18

CONCENTRATIONS OF ZINC (ug/g) IN TREMBLING ASPEN FOLIAGE SAMPLES COLLECTED IN THE TIMMINS AREA

		Year							
	Sample Location	1970	1971	1972	1973	1974	1975	1976	1977
1	900 m NE	-	-	-	-	-	-	333	330
2	Plot 1	-	-	-	-	1950	1502	1073	310
3	Plot 2	-	-	-	-	515	493	301	-
4	Plot 3	-	-	-	-	-	-	349	-
5	Old Plot 3	300	507	-	614	820	425	728	-
6	Plot 4	270	186	253	147	186	377	330	-
7	Plot 5	265	240	262	279	358	397	327	-
8	Old Plot 1	280	314	470	550	710	-	482	-
9	Plot 6	266	281	207	189	256	256	198	-
10	Plot 7	152	132	155	109	222	185	182	-
11	100 m S	-	-	-	-	1300	1672	2415	1317
12	1000 m S	-	-	-	-	-	-	380	360
13	Plot 8	-	-	-	-	504	318	425	247
14	Plot 8A	-	-	-	-	-	-	277	210
15	Plot 9	-	-	-	-	234	450	333	-
16	Plot 10	310	227	191	147	260	256	176	-
	Control	-	-	-	-	230	453	298	-

TABLE 19

CONCENTRATIONS OF COPPER (ug/g) IN TREMBLING ASPEN FOLIAGE

SAMPLES COLLECTED IN THE TIMMINS AREA

		Year							
	Sample Location	1970	1971	1972	1973	1974	1975	1976	1977
1	900 m NE	-	-	-	-	-	-	16	21
2	Plot 1	-	-	-	-	61	87	63	16
3	Plot 2	-	-	-	-	14	13	8	-
4	Plot 3	-	-	-	-	-	-	9	-
5	Old Plot 3	300	14	-	13	16	13	33	-
6	Plot 4		9	9	9	9	11	8	-
7	Plot 5		9	13	4	11	11	11	-
8	Old Plot 1		13	15	13	10	-	18	-
9	Plot 6		8	8	4	8	10	8	-
10	Plot 7		7	8	8	9	8	6	-
11	100 m S	-	-	-	-	35	76	64	162
12	1000 m S	-	-	-	-	-	-	11	7
13	Plot 8		-	-	-	16	12	12	8
14	Plot 8A		-	-	-	-	-	11	5
15	Plot 9		-	-	-	7	10	10	-
16	Plot 10		8	10	8	9	10	4	-
	Control Plot II		-	-	-	9	13	8	-
	Control Plot 12								

TABLE 20

CONCENTRATIONS OF CADMIUM (ug/g) IN TREMBLING ASPEN FOLIAGE SAMPLES COLLECTED IN THE TIMMINS AREA

		Year							
	Sample Location	1970	1971	1972	1973	1974	1975	1976	1977
1	900 m NE	-	-	-	-	-	-	2.3	4.1
2	Plot 1	-	-	-	-	7.5	7.5	8.9	1.4
3	Plot 2	-	-	-	-	1.5	3.1	2.2	-
4	Plot 3	-	-	-	-	-	-	2.1	-
5	Old Plot 3	1.1	2.4	-	2.8	6.0	3.4	6.9	-
6	Plot 4	.3	.8	1.6	1.0	1.5	1.9	2.0	-
7	Plot 5	.6	1.2	1.2	.4	3.0	-	2.8	-
8	Old Plot 1	.5	1.3	2.2	2.1	3.0	-	3.4	-
9	Plot 6	.7	2.1	1.6	.8	2.0	2.3	2.0	-
10	Plot 7	.1	.3	1.0	.5	1.0	1.0	.9	-
11	100 m S	-	-	-	-	5.0	6.0	17.7	15.5
12	1000 m S	-	-	-	-	-	-	2.8	2.1
13	Plot 8	-	-	-	-	1.0	1.6	2.5	2.9
14	Plot 8A	-	-	-	-	-	-	2.3	1.3
15	Plot 9	-	-	-	-	1.0	1.5	1.6	-
16	Plot 10	.7	.9	1.9	.7	1.0	1.3	1.0	-
	Control	-	-	-	-	1.0	2.8	2.4	-

TABLE 21

CONCENTRATIONS OF LEAD (ug/g) IN TREMBLING ASPEN FOLIAGE SAMPLES COLLECTED IN THE TIMMINS AREA

		Year						
	Sample Location	1971	1972	1973	1974	1975	1976	1977
1	900 m NE	-	-	-	-	-	8	12
2	Plot 1	-	-	-	29	37	32	5
3	Plot 2	-	-	-	9	8	4	-
4	Plot 3	-	-	-	-	-	6	-
5	Old Plot 3	10	-	8	15	9	14	-
6	Plot 4	4	18	9	10	7	7	-
7	Plot 5	6	17	5	10	7	7	-
8	Old Plot 1	6	22	7	18	-	12	-
9	Plot 6	8	14	6	12	10	8	-
10	Plot 7	4	7	7	6	4	4	-
11	100 m S	-	-	-	20	22	41	47
12	1000 m S	-	-	-	-	-	7	3
13	Plot 8	-	-	-	13	8	8	5
14	Plot 8A	-	-	-	-	-	7	2
15	Plot 9	-	-	-	7	7	6	-
16	Plot 10	5	11	15	10	10	6	-
	Control	-	-	-	6	10	5	-

TABLE 22

CONCENTRATIONS OF ARSENIC (ug/g) IN TREMBLING ASPEN FOLIAGE

SAMPLES COLLECTED IN THE TIMMINS AREA

		Year						
	Sample Location	1970	1971	1972	1973	1975	1976	1977
1	900 m NE	-	-	-	-	-	.6	.9
2	Plot 1	-	-	-	-	4.6	3.5	.5
3	Plot 2	-	-	-	-	.4	.3	-
4	Plot 3	-	-	-	-	-	<.3	-
5	Old Plot 3	.5	.8	-	.3	.3	.5	-
6	Plot 4	.7	.5	.8	.3	.3	.3	-
7	Plot 5	.5	.6	.5	.3	.3	.4	-
8	Old Plot 1	.5	1.3	.8	.4	-	.8	-
9	Plot 6	.5	.9	.6	.5	.3	.3	-
10	Plot 7	.5	.8	.6	.2	.3	<.3	-
11	100 m S	-	-	-	-	-	6.0	4.8
12	1000 m S	-	-	-	-	-	.7	<.3
13	Plot 8	-	-	-	-	.3	.4	<.3
14	Plot 8A	-	-	-	-	-	.3	<.3
15	Plot 9	-	-	-	-	.5	1.5	-
16	Plot 10	.6	.9	.8	.4	.3	<.3	-
	Control	-	-	-	-	.3	<.3	-

TABLE 23

CONCENTRATIONS OF ZINC (ug/g) IN SOIL SAMPLES
COLLECTED IN THE TIMMINS AREA

Sample Location		Sample Depth (cm)	1970	1971	1972	1973	1974	1975	1976	1977
1	900m NE	0-5	-	-	-	-	-	-	182	1,060
		5-10	-	-	-	-	-	-	122	780
		10-15	-	-	-	-	-	-	105	747
2	Plot 1	0-5	-	-	-	-	1,513	1,355	1,346	3,060
		5-10	-	-	-	-	177	178	271	96
		10-15	-	-	-	-	35	119	154	69
3	Plot 2	0-5	-	-	-	-	58	110	62	155
		5-10	-	-	-	-	30	39	39	26
		10-15	-	-	-	-	22	21	39	20
4	Plot 3	0-5	-	-	-	-	-	155	162	-
		5-10	-	-	-	-	-	70	73	-
		10-15	-	-	-	-	-	59	79	-
5	Old Plot 3	0-5	51	775	1,175	1,250	264	975	804	-
		5-10	-	-	-	869	108	284	241	-
		10-15	-	-	-	938	50	96	93	-
6	Plot 4	0-5	42	81	34	67	38	44	79	-
		5-10	-	-	-	39	58	39	28	-
		10-15	-	-	-	38	40	38	21	-
7	Plot 5	0-5	100	234	147	168	175	187	183	-
		5-10	-	-	-	103	125	140	123	-
		10-15	-	-	-	100	122	93	89	-
8	Old Plot 1	0-5	280	238	327	681	1,338	440	1,168	-
		5-10	-	-	-	124	168	100	194	-
		10-15	-	-	-	74	187	80	119	-
9	Plot 6	0-5	132	201	132	67	115	148	143	-
		5-10	-	-	-	227	97	112	107	-
		10-15	-	-	-	88	98	92	98	-

TABLE 23 (Cont'd)

Sample Location	Sample Depth (cm)	1970	1971	1972	1973	1974	1975	1976	1977
10 Plot 7	0-5	39	61	25	57	32	43	22	-
	5-10	-	-	-	53	33	22	16	-
	10-15	-	-	-	187	30	31	21	-
11 100m S	0-5	-	-	-	1,290	380	1,400	6,700	17,900
	5-10	-	-	-	220	610	213	848	673
	10-15	-	-	-	135	205	131	708	154
12 1000m S	0-5	-	-	-	-	-	-	758	650
	5-10	-	-	-	-	-	-	235	467
	10-15	-	-	-	-	-	-	82	335
13 Plot 8	0-5	-	-	-	-	332	716	565	457
	5-10	-	-	-	-	76	236	150	137
	10-15	-	-	-	-	148	165	110	116
14 Plot 8A	0-5	-	-	-	-	-	-	170	438
	5-10	-	-	-	-	-	-	87	98
	10-15	-	-	-	-	-	-	81	102
15 Plot 9	0-5	-	-	-	-	95	210	262	-
	5-10	-	-	-	-	91	122	88	-
	10-15	-	-	-	-	68	104	71	-
16 Plot 10	0-5	36	40	63	49	-	104	59	-
	5-10	-	-	-	29	50	43	28	-
	10-15	-	-	-	21	43	39	29	-
17 Control	0-5	-	-	-	-	170	182	149	-
	5-10	-	-	-	-	160	134	123	-
	10-15	-	-	-	-	120	124	118	-

TABLE 24

CONCENTRATIONS OF COPPER (ug/g) IN SOIL SAMPLES
COLLECTED IN THE TIMMINS AREA

Sample Location		Sample Depth (cm)	1971	1972	1973	1974	1975	1976	1977
1	900m NE	0-5	-	-	-	-	-	38	197
		5-10	-	-	-	-	-	34	123
		10-15	-	-	-	-	-	36	134
2	Plot 1	0-5	-	-	-	345	334	293	421
		5-10	-	-	-	40	51	56	26
		10-15	-	-	-	26	37	40	27
3	Plot 2	0-5	-	-	-	22	26	21	29
		5-10	-	-	-	19	16	14	4
		10-15	-	-	-	13	12	7	4
4	Plot 3	0-5	-	-	-	-	43	39	-
		5-10	-	-	-	-	20	19	-
		10-15	-	-	-	-	21	25	-
5	Old Plot 3	0-5	289	-	346	108	384	227	-
		5-10	-	-	226	43	44	43	-
		10-15	-	-	226	34	24	23	-
6	Plot 4	0-5	17	15	23	23	25	24	-
		5-10	-	-	12	22	22	15	-
		10-15	-	-	10	18	19	12	-
7	Plot 5	0-5	27	19	25	42	39	30	-
		5-10	-	-	16	35	27	17	-
		10-15	-	-	18	28	24	17	-
8	Old Plot 1	0-5	56	88	182	469	112	260	-
		5-10	-	-	21	42	26	37	-
		10-15	-	-	20	31	24	29	-
9	Plot 6	0-5	31	20	13	38	33	25	-
		5-10	-	-	13	32	28	23	-
		10-15	-	-	18	35	30	23	-

TABLE 24 (Cont'd)

Sample Location	Sample Depth (cm)	1971	1972	1973	1974	1975	1976	1977
10 Plot 7	0-5	4	6	7	12	17	4	-
	0-10	-	-	7	13	11	3	-
	10-15	-	-	4	12	12	5	-
11 100m S	0-5	-	-	128	45	118	428	475
	5-10	-	-	28	58	38	75	58
	10-15	-	-	18	28	45	70	36
12 1000m S	0-5	-	-	-	-	-	75	67
	5-10	-	-	-	-	-	30	53
	10-15	-	-	-	-	-	18	45
13 Plot 8	0-5	-	-	-	112	145	108	190
	5-10	-	-	-	42	78	55	69
	10-15	-	-	-	52	56	61	47
14 Plot 8A	0-5	-	-	-	-	-	38	46
	5-10	-	-	-	-	-	33	27
	10-15	-	-	-	-	-	33	35
15 Plot 9	0-5	-	-	-	33	55	55	-
	5-10	-	-	-	33	42	40	-
	10-15	-	-	-	32	41	37	-
16 Plot 10	0-5	9	14	18	-	32	19	-
	5-10	-	-	11	15	20	19	-
	10-15	-	-	8	10	16	27	-
17 Control	0-5	-	-	-	48	61	49	-
	5-10	-	-	-	40	49	36	-
	10-15	-	-	-	33	48	33	-

TABLE 25

CONCENTRATIONS OF CADMIUM (ug/g) IN SOIL SAMPLES COLLECTED IN THE TIMMINS AREA

Sample Location		Sample Depth (cm)	1970	1971	1972	1973	1974	1975	1976	1977
1	900m NE	0-5	-	-	-	-	-	-	1.4	6.6
		5-10	-	-	-	-	-	-	1.2	3.6
		10-15	-	-	-	-	-	-	1.2	3.8
2	Plot 1	0-5	-	-	-	-	12.0	9.5	10.7	19.2
		5-10	-	-	-	-	3.0	1.7	1.9	2.3
		10-15	-	-	-	-	3.0	1.3	1.0	1.2
3	Plot 2	0-5	-	-	-	-	ND	1.2	.9	.9
		5-10	-	-	-	-	ND	.8	.6	.3
		10-15	-	-	-	-	ND	.8	.5	.3
4	Plot 3	0-5	-	-	-	-	-	4.4	1.3	-
		5-10	-	-	-	-	-	3.5	1.0	-
		10-15	-	-	-	-	-	3.2	1.0	-
5	Old Plot 3	0-5	.1	.3	.7	9.7	4.0	11.5	6.2	-
		5-10	-	-	-	5.9	ND	4.2	1.8	-
		10-15	-	-	-	2.8	ND	4.0	1.0	-
6	Plot 4	0-5	.2	.3	.5	1.9	3.0	1.6	1.7	-
		5-10	-	-	-	.9	4.0	1.2	1.2	-
		10-15	-	-	-	.7	4.0	1.2	.9	-
7	Plot 5	0-5	.1	.6	1.0	2.4	4.0	1.6	1.8	-
		5-10	-	-	-	.9	4.0	1.5	1.3	-
		10-15	-	-	-	1.1	4.0	1.5	1.4	-
8	Old Plot 1	0-5	.2	.3	.9	4.7	9.0	4.7	9.1	-
		5-15	-	-	-	1.1	4.0	3.7	1.5	-
		10-15	-	-	-	2.1	4.0	3.3	1.3	-
9	Plot 6	0-5	.2	.3	.7	2.0	4.0	1.9	1.8	-
		5-10	-	-	-	.7	4.0	1.4	1.3	-
		10-15	-	-	-	.7	4.0	1.4	1.2	-

TABLE 25 (Cont'd)

Sample Location	Sample Depth (cm)	1970	1971	1972	1973	1974	1975	1976	1977
10 Plot 7	0-5	.2	.3	.6	1.8	ND	1.1	.9	-
	5-10	-	-	-	.6	5.0	1.0	.8	-
	10-15	-	-	-	.7	5.0	.9	.6	-
11 100m S	0-5	-	-	-	8	6	6	30	41
	5-10	-	-	-	3	6	2	4	3
	10-15	-	-	-	>3	4	3	4	3
12 1000m S	0-5	-	-	-	-	-	-	5.2	4.5
	5-10	-	-	-	-	-	-	2.1	3.1
	10-15	-	-	-	-	-	-	1.2	2.3
13 Plot 8	0-5	-	-	-	-	6.0	5.5	4.5	2.1
	5-10	-	-	-	-	4.0	2.6	1.8	.5
	10-15	-	-	-	-	4.0	1.9	1.7	<.5
14 Plot 8A	0-5	-	-	-	-	-	-	1.5	3.2
	5-10	-	-	-	-	-	-	1.0	1.4
	10-15	-	-	-	-	-	-	1.1	1.4
15 Plot 9	0-5	-	-	-	-	4.0	2.5	2.5	-
	5-10	-	-	-	-	4.0	1.9	1.6	-
	10-15	-	-	-	-	3.0	1.8	1.4	-
16 Plot 10	0-5	.2	.4	.5	3.0	-	1.5	1.2	-
	5-10	-	-	-	.9	3.0	1.0	.6	-
	10-15	-	-	-	.7	ND	1.0	.6	-
17 Control	0-5	-	-	-	-	3.0	1.7	1.2	-
	5-10	-	-	-	-	3.0	1.5	1.1	-
	10-15	-	-	-	-	3.0	1.6	1.1	-

TABLE 26

CONCENTRATIONS OF LEAD (ug/g) IN SOIL SAMPLES
COLLECTED IN THE TIMMINS AREA

Sample Location		Sample Depth (cm)	1971	1972	1973	1974	1975	1976	1977
1	900m NE	0-5	-	-	-	-	-	65	73
		5-10	-	-	-	-	-	46	55
		10-15	-	-	-	-	-	33	55
2	Plot 1	0-5	-	-	-	63	82	87	117
		5-10	-	-	-	14	29	30	9
		10-15	-	-	-	15	25	32	9
3	Plot 2	0-5	-	-	-	17	13	17	17
		5-10	-	-	-	14	8	10	4
		10-15	-	-	-	11	7	8	6
4	Plot 3	0-5	-	-	-	-	45	25	-
		5-10	-	-	-	-	34	20	-
		10-15	-	-	-	-	32	18	-
5	Old Plot 3	0-5	49	52	32	20	55	49	-
		5-10	-	-	37	13	31	26	-
		10-15	-	-	41	15	29	18	-
6	Plot 4	0-5	17	23	24	25	18	31	-
		5-10	-	-	14	24	14	20	-
		10-15	-	-	12	19	12	17	-
7	Plot 5	0-5	31	35	28	40	49	32	-
		5-10	-	-	22	36	19	24	-
		10-15	-	-	23	32	21	25	-
8	Old Plot 1	0-5	37	38	50	89	42	93	-
		5-10	-	-	22	33	32	29	-
		10-15	-	-	20	22	32	31	-
9	Plot 6	0-5	37	27	12	43	35	38	-
		5-10	-	-	24	38	23	32	-
		10-15	-	-	22	39	27	30	-

TABLE 26 (Cont'd)

Sample Location	Sample Depth (cm)	1971	1972	1973	1974	1975	1976	1977
10 Plot 7	0-5	8	23	15	18	22	18	-
	5-10	-	-	5	12	10	13	-
	10-15	-	-	8	12	10	12	-
11 100m S	0-5	-	-	28	48	56	188	230
	5-10	-	-	18	53	34	42	45
	10-15	-	-	20	35	34	45	29
12 1000m S	0-5	-	-	-	-	-	32	44
	5-10	-	-	-	-	-	19	37
	10-15	-	-	-	-	-	11	33
13 Plot 8	0-5	-	-	-	55	58	54	49
	5-10	-	-	-	32	39	32	32
	10-15	-	-	-	42	39	29	28
14 Plot 8A	0-5	-	-	-	-	-	39	53
	5-10	-	-	-	-	-	33	28
	10-15	-	-	-	-	-	32	23
15 Plot 9	0-5	-	-	-	38	57	62	-
	5-10	-	-	-	37	37	24	-
	10-15	-	-	-	29	33	25	-
16 Plot 10	0-5	14	34	42	-	61	52	-
	5-10	-	-	14	23	20	17	-
	10-15	-	-	11	13	19	12	-
17 Control	0-5	-	-	-	35	31	24	-
	5-10	-	-	-	35	29	24	-
	10-15	-	-	-	28	31	26	-

TABLE 27

CONCENTRATIONS OF ARSENIC (ug/g) IN SOIL SAMPLES COLLECTED IN THE TIMMINS AREA

Sample Location		Sample Depth (cm)	1970	1971	1972	1973	1975	1976	1977
1	900m NE	0-5	-	-	-	-	-	3.0	7.1
		5-10	-	-	-	-	-	3.0	5.8
		10-15	-	-	-	-	-	3.1	5.8
2	Plot 1	0-5	-	-	-	-	6.1	7.6	8.5
		5-10	-	-	-	-	2.6	2.7	3.9
		10-15	-	-	-	-	2.3	3.0	1.8
3	Plot 2	0-5	-	-	-	-	1.7	1.2	1.2
		5-10	-	-	-	-	1.6	1.0	.6
		10-15	-	-	-	-	1.2	.7	.6
4	Plot 3	0-5	-	-	-	-	1.4	1.8	-
		5-10	-	-	-	-	.9	1.7	-
		10-15	-	-	-	-	1.0	1.9	-
5	Old Plot 3	0-5	1.9	1.0	1.3	4.8	3.1	1.0	-
		5-10	-	-	-	4.0	2.9	1.8	-
		10-15	-	-	-	3.5	1.8	.8	-
6	Plot 4	0-5	.5	1.8	.9	2.6	1.4	1.6	-
		5-10	-	-	-	1.6	1.4	1.3	-
		10-15	-	-	-	1.3	1.4	1.4	-
7	Plot 5	0-5	.5	.8	.8	2.6	2.9	2.0	-
		5-10	-	-	-	2.3	2.7	2.1	-
		10-15	-	-	-	.3	2.9	2.5	-
8	Old Plot 1	0-5	.5	1.5	.7	4.2	-	5.9	-
		5-10	-	-	-	4.0	-	3.3	-
		10-15	-	-	-	3.8	-	3.7	-
9	Plot 6	0-5	.5	.8	.7	2.6	3.7	2.7	-
		5-10	-	-	-	3.0	3.4	2.8	-
		10-15	-	-	-	3.4	3.6	3.0	-

TABLE 27 (Cont'd)

Sample Location	Sample Depth (cm)	1970	1971	1972	1973	1975	1976	1977
10 Plot 7	0-5	.5	.8	.9	.6	2.1	.7	-
	5-10	-	-	-	.6	1.1	.7	-
	10-15	-	-	-	.6	1.0	.8	-
11 100mS	0-5	-	-	-	-	-	17.4	28
	5-10	-	-	-	-	-	2.5	5
	10-15	-	-	-	-	-	3.9	4
12 1000m S	0-5	-	-	-	-	-	3.0	5.0
	5-10	-	-	-	-	-	1.6	3.6
	10-15	-	-	-	-	-	1.3	3.9
13 Plot 8	0-5	-	-	-	-	6.8	3.9	5.8
	5-10	-	-	-	-	4.2	1.8	4.8
	10-15	-	-	-	-	4.3	2.4	4.5
14 Plot 8A	0-5	-	-	-	-	-	5.4	28.1
	5-10	-	-	-	-	-	3.9	66.9
	10-15	-	-	-	-	-	4.3	60.1
15 Plot 9	0-5	-	-	-	-	6.9	5.4	-
	5-10	-	-	-	-	5.4	2.6	-
	10-15	-	-	-	-	4.1	2.0	-
16 Plot 10	0-5	.9	1.3	.6	3.0	9.1	5.8	-
	5-10	-	-	-	1.7	1.5	3.1	-
	10-15	-	-	-	1.4	.5	2.7	-
17 Control	0-5	-	-	-	-	2.9	2.7	-
	5-10	-	-	-	-	3.0	2.8	-
	10-15	-	-	-	-	2.5	3.2	-

TABLE 28

INJURY TO VEGETATION OBSERVED AT RAILROAD SITE 1

TIMMINS IN 1975 and 1976

Species	Symptom	Severity		
		July 1975	August 1975	June 1976
Raspberry	Particulate	Light	-	-
	Anthocyanosis	Light	Moderate	-
	Marginal chlorosis	Moderate	Light-Moderate	Light
	Marginal necrosis	-	Light-Moderate	Light
Elderberry	Marginal necrosis	-	Light	Light
	Marginal and Intercostal chlorosis	-	Light	Light
Aster	Marginal Anthocyanosis	Light-Moderate	Light	-
	Particulate	Light	Light	Moderate
	Intercostal necrosis	None	-	Moderate
Fireweed	Leaf spotting	Light	Light	-
	Marginal chlorosis	-	Moderate	Healthy
Serviceberry	Particulate	Light	-	-
	Marginal necrosis	-	Severe	Healthy
Diervilla Lonicera	Particulate	Light	-	-
	Anthocyanosis	-	Light-Moderate	Healthy
Bindweed	Particulate	Light	-	-
	Anthocyanosis	Severe	Severe	Light

TABLE 29

CONCENTRATIONS OF CHEMICAL ELEMENTS IN VEGETATION

COLLECTED AT RAILROAD SITE 1 - TIMMINS*

		Element (ppm)				
Species	Date	Zn	Cu	Cd	Pb	As
Raspberry	June 1975	777	67	4.1	23	1.3
	July 1975	1390	105	9.8	38	-
	Control	125	6	1.0	21	
Trembling Aspen	July 1975	1433	37	9.8	18	
	Control	200	9	1.0	9	

* Values reported are means of triplicate samples

TABLE 30

TIMMINS RAILROAD STUDY
CONCENTRATION OF ZINC (ppm) IN SOIL*

Site	Distance** (m)	Soil Depth (cm) 0-5		5-10		10-15	
		1975	1976	1975	1976	1975	1976
1	0	4377	5543	795	488	213	229
	50	970	1125	94	178	163	99
	100	1337	1850	234	236	117	129
2	0	442	405	114	64	72	54
	50	369	199	177	59	62	62
	100	271	214	104	115	67	106
3	0	309	448	29	49	20	12
	50	234	213	36	78	39	32
	100	132	136	61	21	27	15
4	0	5710	2580	746	1683	417	313
	50	254	506	75	319	131	15
	100	148	107	60	67	23	177
5	0	492	462	158	145	65	48
	50	141	123	75	60	56	42
	100	102	168	65	52	59	43
6	0	530	2117	183	167	64	460
	50	463	338	141	113	122	88
	100	234	190	123	122	116	77
Control		182		134		124	

* Values reported means of triplicate samples.

** Distance from Railroad property line.

TABLE 31

TIMMINS RAILROAD STUDY
CONCENTRATION OF COPPER (ppm) IN SOIL*

Site	Distance** (m)	Soil Depth (cm) 0-5		5-10		10-15	
		1975	1976	1975	1976	1975	1976
1	0	1033	1193	180	64	104	48
	50	166	171	24	41	33	29
	100	229	179	46	51	36	40
2	0	157	145	46	34	35	33
	50	153	68	56	28	28	35
	100	72	73	19	30	13	23
3	0	111	98	6	14	5	6
	50	50	44	14	18	13	14
	100	25	35	10	10	13	10
4	0	1433	721	138	416	78	86
	50	55	120	18	77	27	5
	100	23	13	10	14	5	34
5	0	102	113	23	38	14	22
	50	28	35	14	28	13	22
	100	17	58	10	29	10	15
6	0	273	1027	80	91	31	196
	50	122	106	27	35	22	32
	100	70	62	31	56	29	31
Control		61		49		48	

* Values reported means of triplicate samples.

** Distance from Railroad property line.

TABLE 32

TIMMINS RAILROAD STUDY
CONCENTRATION OF LEAD (ppm) IN SOIL*

Site	Distance** (m)	Soil Depth (cm) 0-5		5-10		10-15	
		1975	1976	1975	1976	1975	1976
1	0	145	149	45	29	29	30
	50	45	43	23	22	27	19
	100	71	77	33	31	29	28
2	0	51	31	30	20	23	23
	50	102	36	57	24	29	25
	100	49	39	32	30	21	29
3	0	13	24	10	9	8	9
	50	18	20	10	11	10	11
	100	13	25	10	9	11	9
4	0	165	123	37	66	23	29
	50	16	25	8	34	9	4
	100	8	49	5	11	ND	24
5	0	20	35	15	27	12	26
	50	20	29	16	26	21	26
	100	14	24	13	21	13	5
6	0	48	102	28	18	27	30
	50	50	35	44	29	29	29
	100	44	24	36	21	30	19
Control		31		29		31	

* Values reported means of triplicate samples.

** Distance from Railroad property line.

TABLE 33

TIMMINS RAILROAD STUDY
CONCENTRATION OF CADMIUM (ppm) IN SOIL*

Site	Distance** (m)	Soil Depth (cm) 0-5		5-10		10-15	
		1975	1976	1975	1976	1975	1976
1	0	29.6	38	5.3	2.6	2.6	1.8
	50	6.0	6.2	1.4	1.9	1.6	0.9
	100	7.7	9.9	2.1	1.7	1.6	0.9
2	0	5.2	3.1	2.4	1.3	1.3	1.3
	50	4.1	1.8	3.9	1.1	3.8	1.1
	100	2.1	1.7	1.0	0.9	0.7	0.9
3	0	2.0	2.5	0.5	0.5	0.5	0.5
	50	1.4	1.4	0.6	0.7	0.8	0.6
	100	0.8	1.1	0.8	<3	1.0	<3
4	0	30.4	16	4.5	10	3.7	3
	50	2.2	0.3	1.3	3	1.3	<3
	100	1.0	<3	0.8	<3	0.5	0.3
5	0	2.7	3	1.3	3	0.9	<3
	50	1.4	<3	1.4	<3	1.4	<3
	100	1.3	1.9	1.0	1.1	0.9	0.7
6	0	3.8	13.5	1.8	1.8	1.8	3.0
	50	3.0	2.3	1.5	1.0	1.5	1.2
	100	2.4	1.9	1.5	1.4	1.5	1.0
Control		1.7		1.5		1.6	

* Values reported means of triplicate samples.

** Distance from Railroad property line.

TABLE 34

TIMMINS RAILROAD STUDY
CONCENTRATION OF ARSENIC (ppm) IN SOIL*

Site	Distance** (m)	Soil Depth (cm) 0-5		5-10		10-15	
		1975	1976	1975	1976	1975	1976
1	0	9.1	12.5	2.9	4.4	2.1	4.7
	50	3.5	3.5	2.3	2.4	2.4	2.1
	100	5.1	5.9	3.3	3.3	2.9	3.0
2	0	6.0	10.8	7.7	7.6	5.9	7.3
	50	78.1	19.3	30.5	28.4	7.7	37.2
	100	2.8	4.3	2.1	3.7	1.7	3.5
3	0	1.1	1.8	0.4	0.8	0.5	0.8
	50	1.6	1.4	1.3	1.0	1.1	1.2
	100	1.4	2.4	0.9	0.9	1.0	0.9
4	0	11.1	12.5	12.6	11.9	8.2	4.0
	50	3.2	21.0	8.1	22.9	4.1	2.0
	100	4.2	3.6	3.4	2.2	1.9	26.5
5	0	1.6	2.4	1.1	2.0	0.9	1.6
	50	1.3	1.8	1.2	1.6	1.1	1.5
	100	1.3	2.3	1.0	1.5	0.9	0.9
6	0	3.1	7.0	1.6	1.4	0.5	3.7
	50	3.7	4.1	3.5	3.8	3.3	4.0
	100	3.4	3.0	3.7	2.7	3.8	2.7
Control		2.9		3.0		2.5	

* Values reported means of triplicate samples.

** Distance from Railroad property line.

TABLE 35

CONCENTRATIONS OF CHEMICAL ELEMENTS IN SOIL SAMPLES COLLECTED IN THE TIMMINS AREA BIOASSAY STUDY - 1976

Soil	Zn (ppm)	Cu (ppm)	Pb (ppm)	Cd (ppm)	As (ppm)	Ca (%)	Mg (%)	K (ppm)
Check	43	15	25	0.5	1.8	0.70	0.37	880
100 m S	1630	100	75	7.0	9.4	0.24	0.43	2100
Railroad 1	2000	493	125	19.0	7.8	0.14	0.45	2400
Railroad 4	2500	493	225	26.0	8.9	0.20	0.10	500

TABLE 36

YIELD AND CONDITION OF CORN PLANTS GROWN IN

SOIL SAMPLES COLLECTED IN THE TIMMINS AREA - 1976

Soil Treatment	Fresh Weight (g)	Dry Weight (g)	Height (cm)	Leaves per Plant	Leaf Mortality (%)	Foliage Condition Rating		
						Chlorosis	Necrosis	Total
Unfertilized*								
Check	16.9	3.34	45	7.0	33.3	0.7	2.1	2.8
100 m S	26.8	5.07	51	8.3	33.3	0.5	2.1	2.6
Railroad 1	34.3	5.60	54	8.0	29.2	0.7	1.8	2.5
Railroad 4	9.4	2.03	41	6.8	44.3	1.2	3.1	4.3
Fertilized								
Check	58.6	10.3	70	8.3	24.0	0.8	1.8	2.6
100 m S	43.7	7.0	57	7.7	34.8	0.7	2.3	2.9
Railroad 1	97.1	16.8	81	9.0	33.3	0.8	2.2	3.0
Railroad 4	18.7	3.7	55	7.7	43.5	1.0	2.9	3.9

* Values reported are means of 3 plants per pot. Unfertilized treatments were completed in triplicate. A single replicate pot was used in the fertilized treatments

TABLE 37

CONCENTRATIONS OF CHEMICAL ELEMENTS IN TISSUES OF CORN PLANTS GROWN IN SOIL SAMPLES COLLECTED IN THE TIMMINS AREA - 1976

Soil Treatment	Plant Part	Element Zn	Cu	Pb	Cd	As
Unfertilized						
Check	Foliage	25	2	5	0.3	0.3
	Roots	24	40	23	0.6	0.3
100 mS	Foliage	105	3	6	1.1	0.3
	Roots	253	52	8	4.3	0.7
Railroad 1	Foliage	380	2	5	2.8	0.3
	Roots	727	145	12	32.7	0.8
Railroad 4	Foliage	1600	7	12	1.3	0.4
	Roots	3147	208	11	8.7	0.3
Fertilized						
Check	Foliage	20	2	5	0.3	0.3
	Roots	20	21	10	0.5	0.3
100 mS	Foliage	140	3	5	1.1	0.3
	Roots	275	42	6	5.4	0.5
Railroad 1	Foliage	400	3	3	2.2	0.3
	Roots	640	181	9	15.0	0.3
Railroad 4	Foliage	2000	12	5	3.1	0.3
	Roots	2800	151	10	12.2	0.3

* Data reported represents mean concentration of respective elements in three replicated treatments with three pooled plants per pot in unfertilized treatment and a single pot of three pooled plants for the fertilized treatment

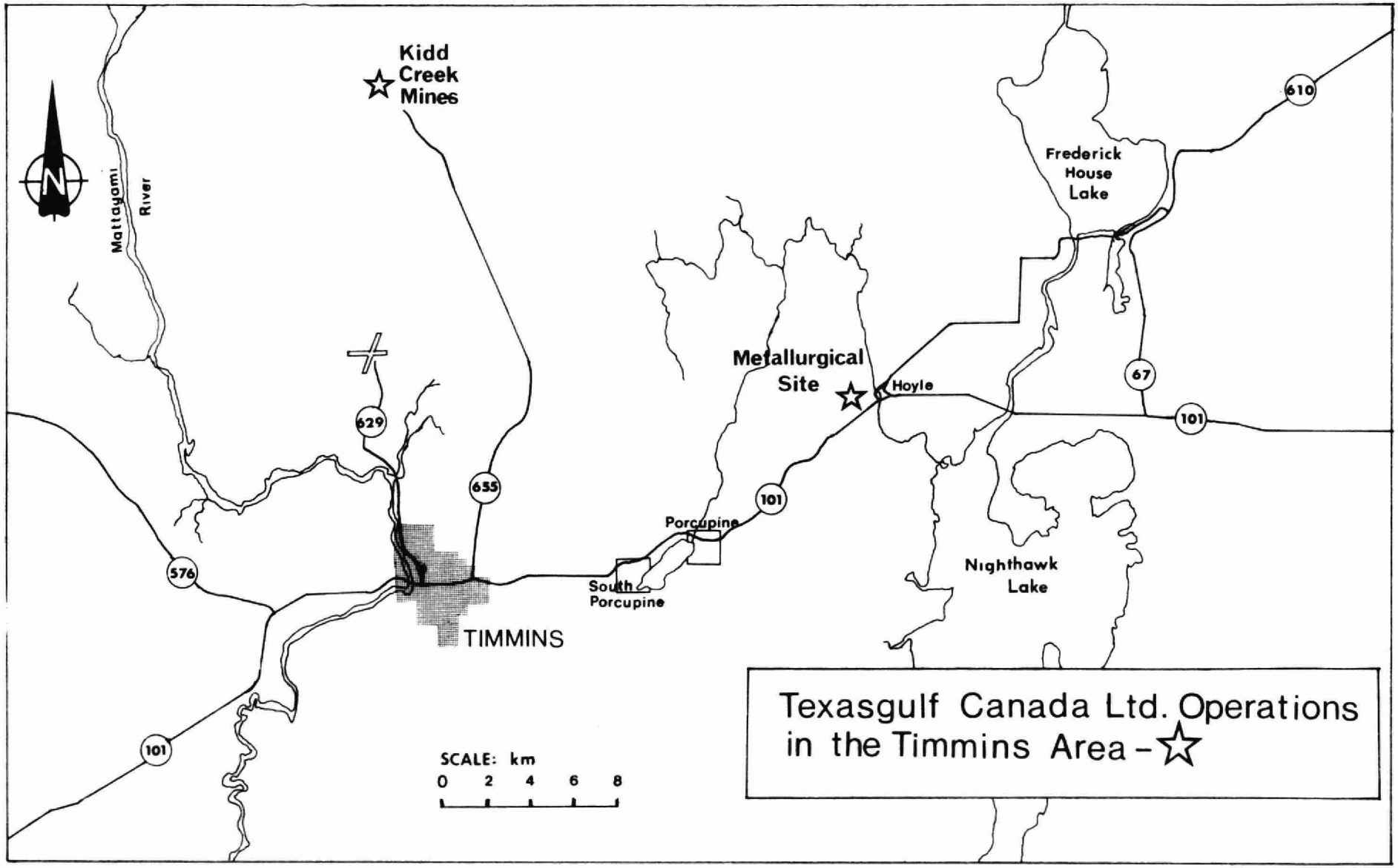

Kidd
Creek
Mines
Mattagami
River
Frederick
House
Lake
610
Metallurgical
Site
Hoyle
67
101
629
655
101
Porcupine
South
Porcupine
576
TIMMINS
Nighthawk
Lake
101
SCALE: km
0 2 4 6 8
Texasgulf Canada Ltd. Operations
in the Timmins Area -

Figure 1

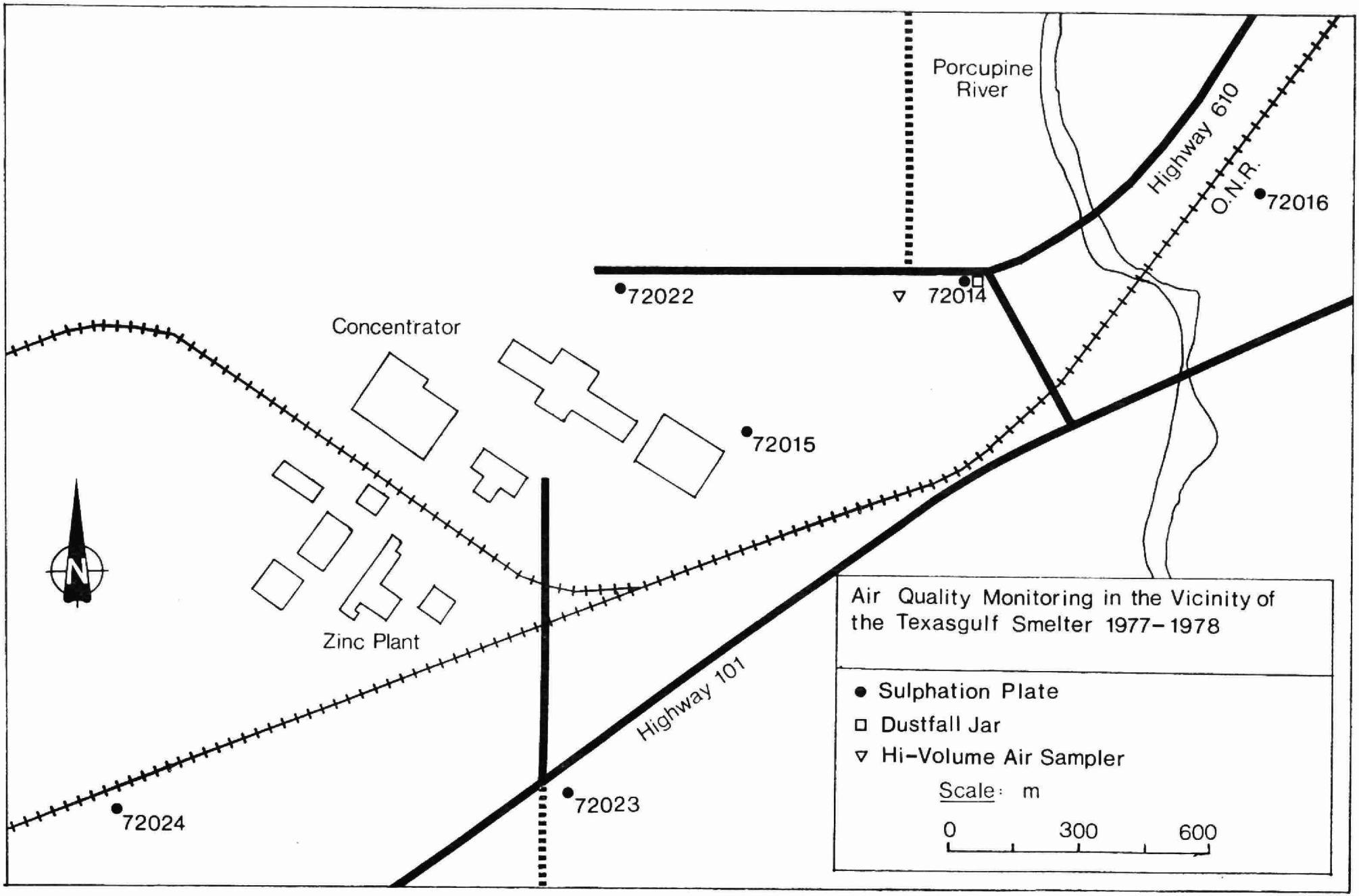

Porcupine River
Highway 610
O.N.R.
72016
72022
72014
Concentrator
72015
N
Zinc Plant
Highway 101
72024
72023
Air Quality Monitoring in the Vicinity of the Texasgulf Smelter 1977–1978
Sulphation Plate
Dustfall Jar
Hi-Volume Air Sampler
Scale: m
0
300
600

Figure 2

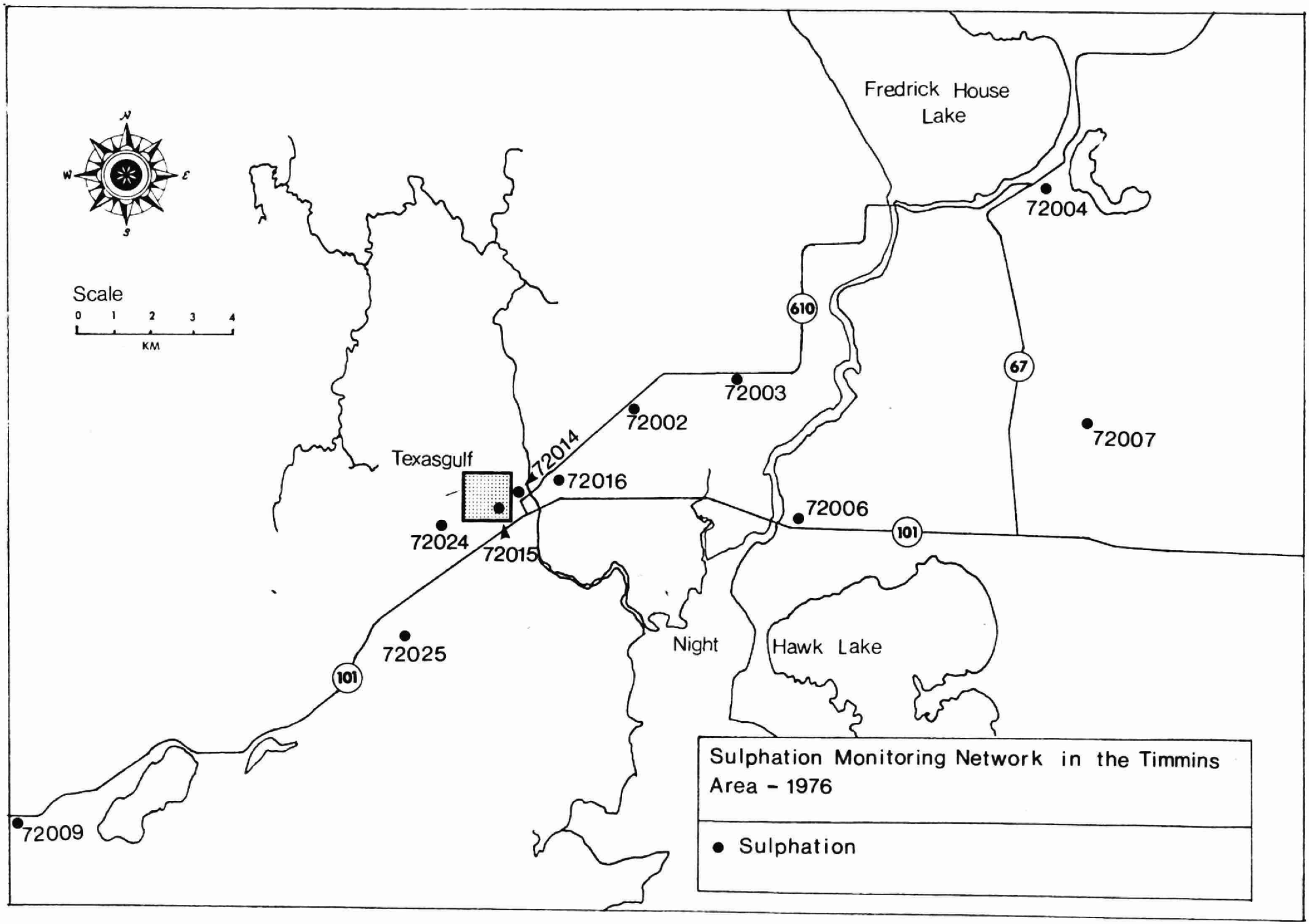

Fredrick House Lake
72004
610
67
72003
72002
72007
Texasgulf
72014
72016
72006
101
72024
72015
72025
Night
Hawk Lake
101
72009
Scale
0 1 2 3 4
KM
Sulphation Monitoring Network in the Timmins Area - 1976
• Sulphation

Figure 3

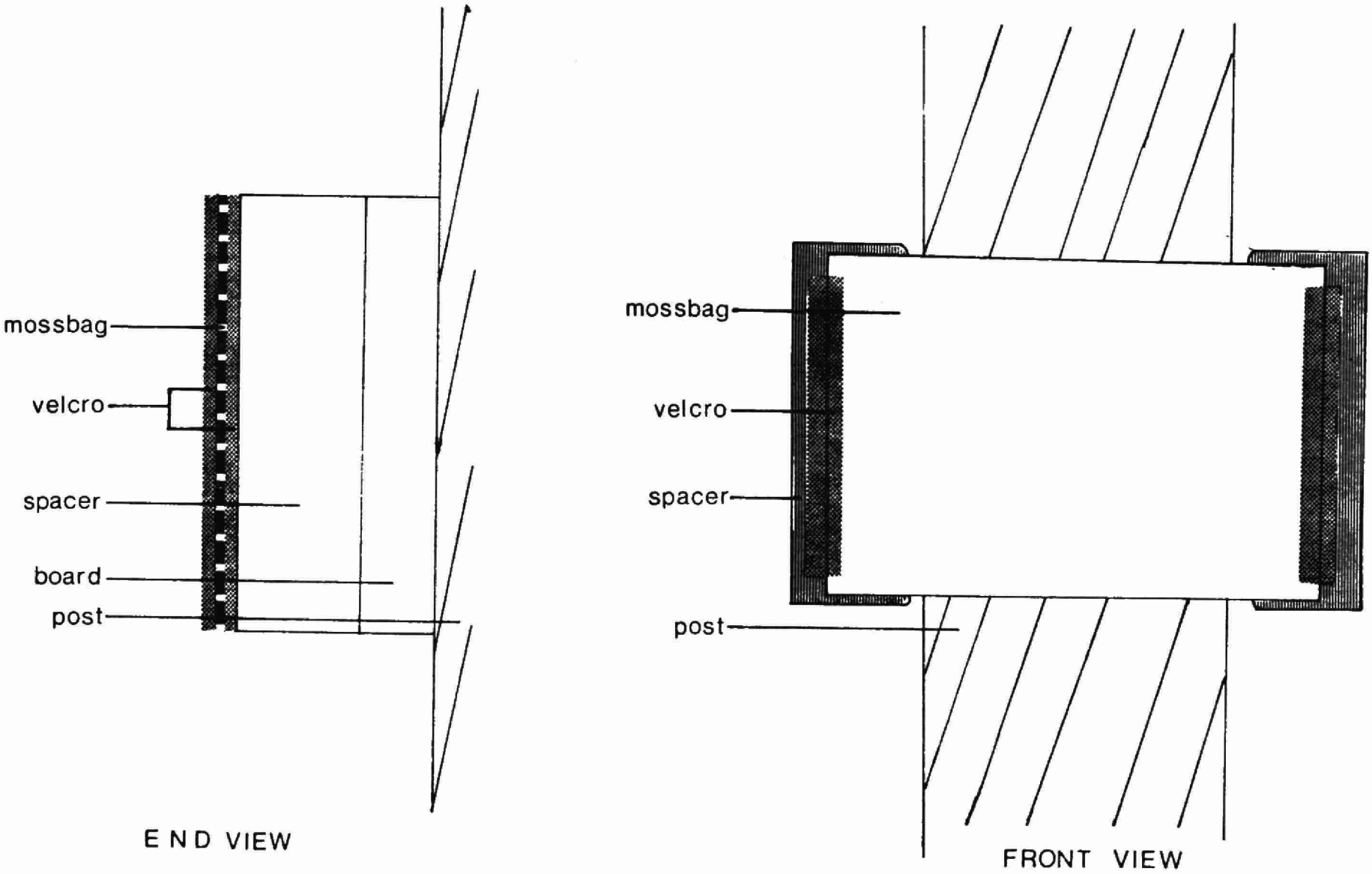
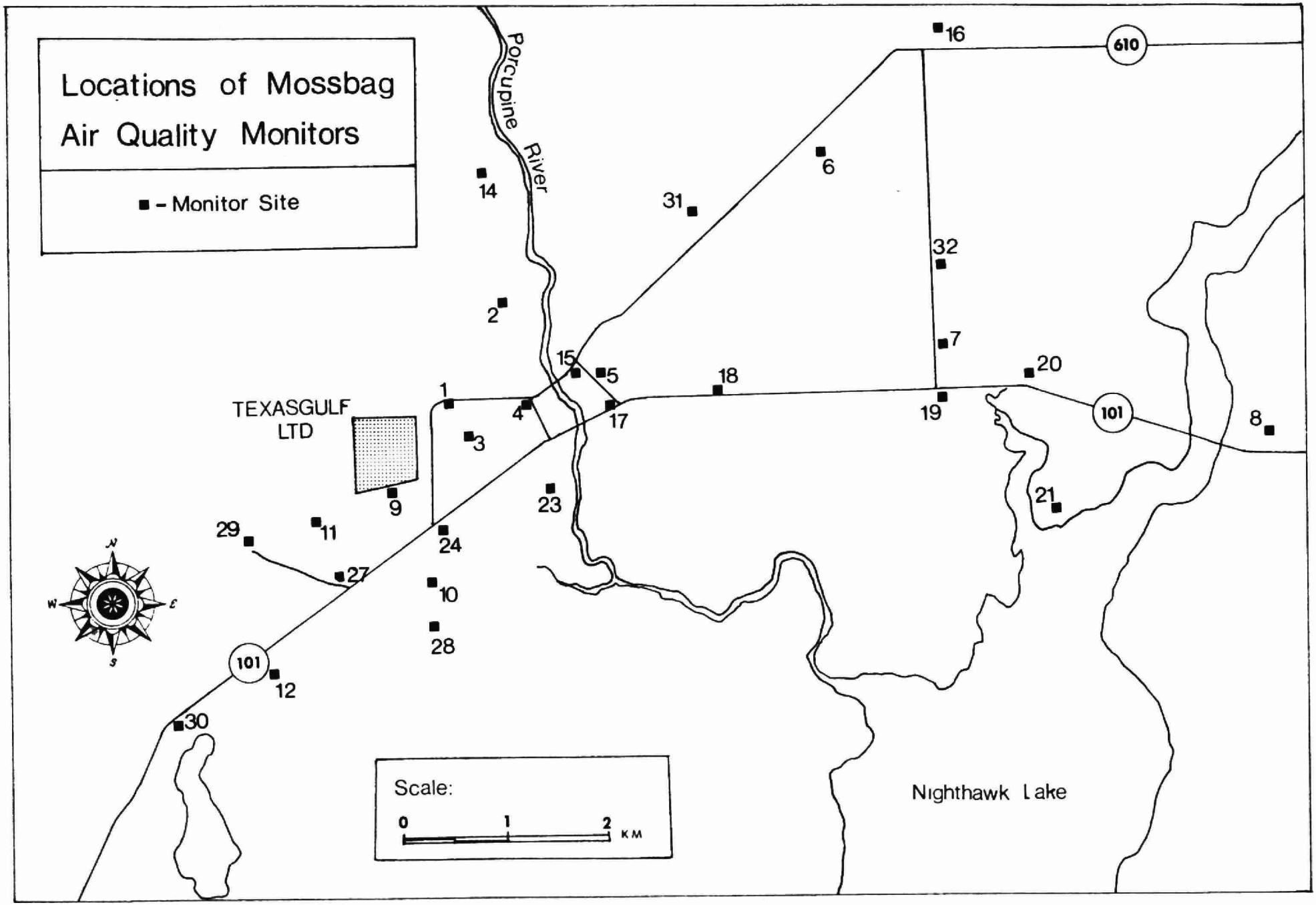


DIAGRAM OF CONSTRUCTION OF MOSSBAG MONITOR

Figure 4


Locations of Mossbag Air Quality Monitors
■ - Monitor Site
Porcupine River
TEXASGULF LTD
610
101
101
Nighthawk Lake
Scale:
0 1 2 KM
N
W
E
S
1
2
3
4
5
6
7
8
9
10
11
12
14
15
16
17
18
19
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21
23
24
27
28
29
30
31
32

Figure 5

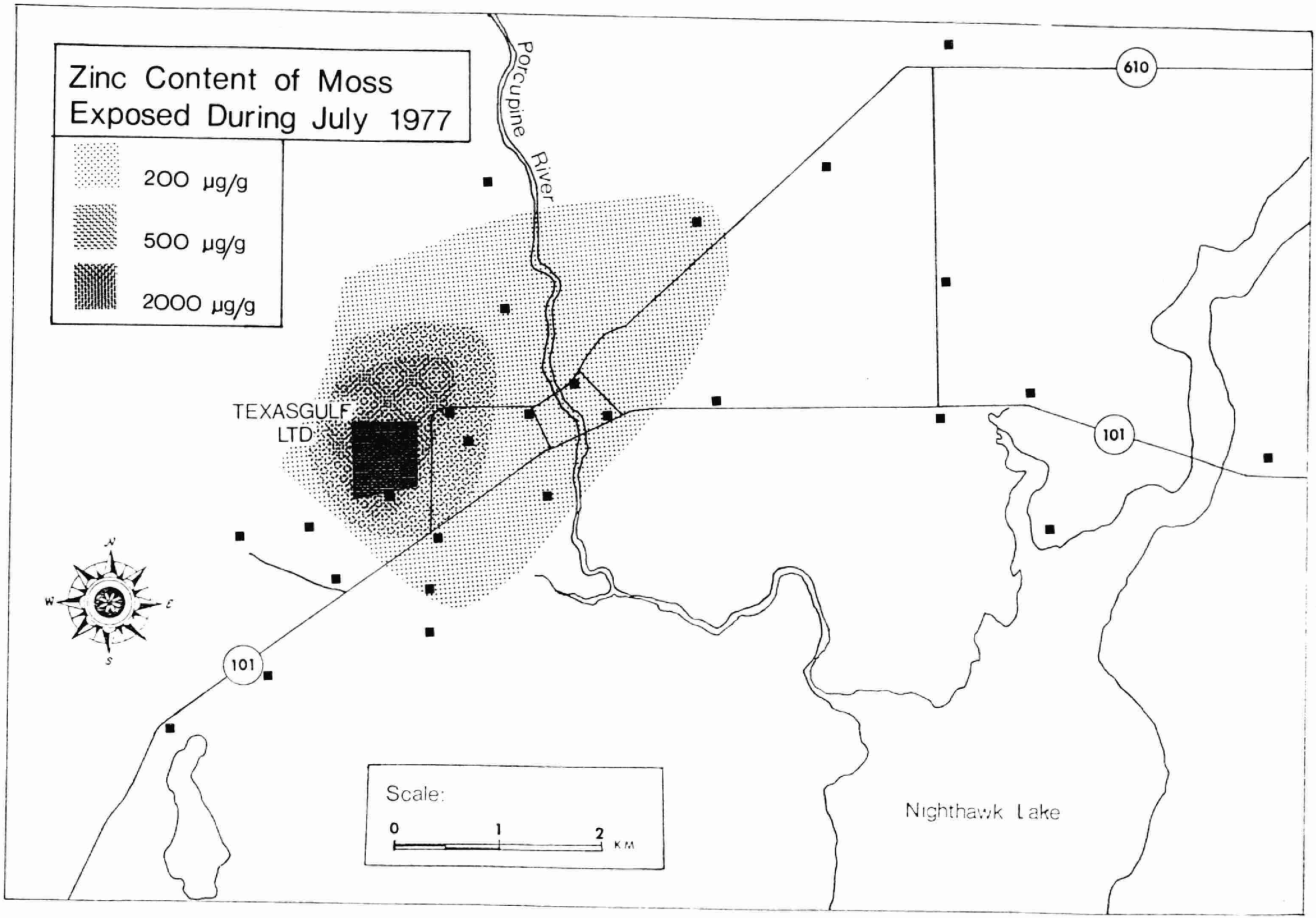

Zinc Content of Moss
Exposed During July 1977
200 µg/g
500 µg/g
2000 µg/g
Porcupine River
TEXASGULF
LTD
610
101
101
N
W
E
S
Scale:
0
1
2
KM
Nighthawk Lake

Figure 6

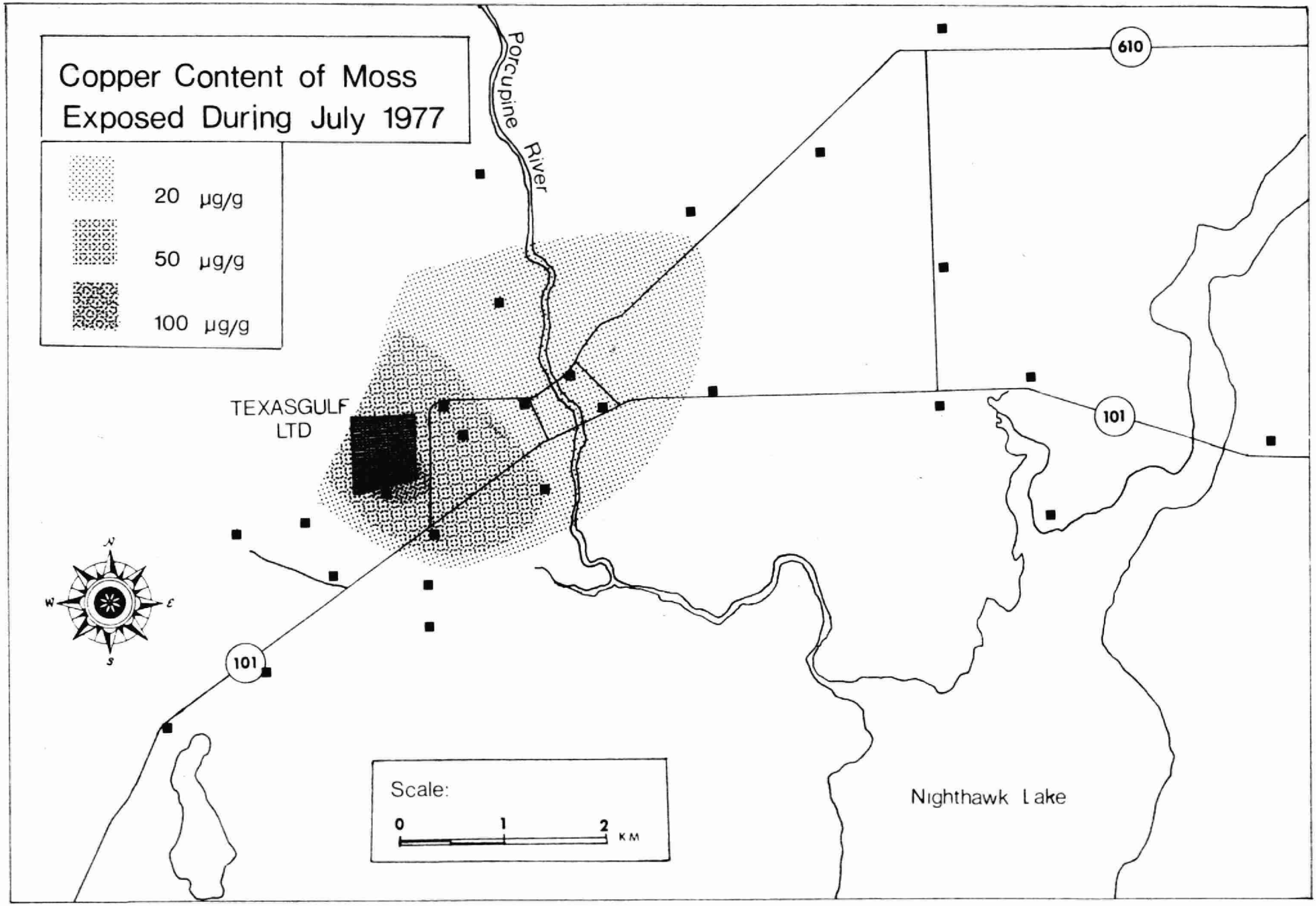

Copper Content of Moss
Exposed During July 1977
20 µg/g
50 µg/g
100 µg/g
Porcupine River
610
101
TEXASGULF
LTD
101
Nighthawk Lake
Scale:
0
1
2
KM

Figure 7

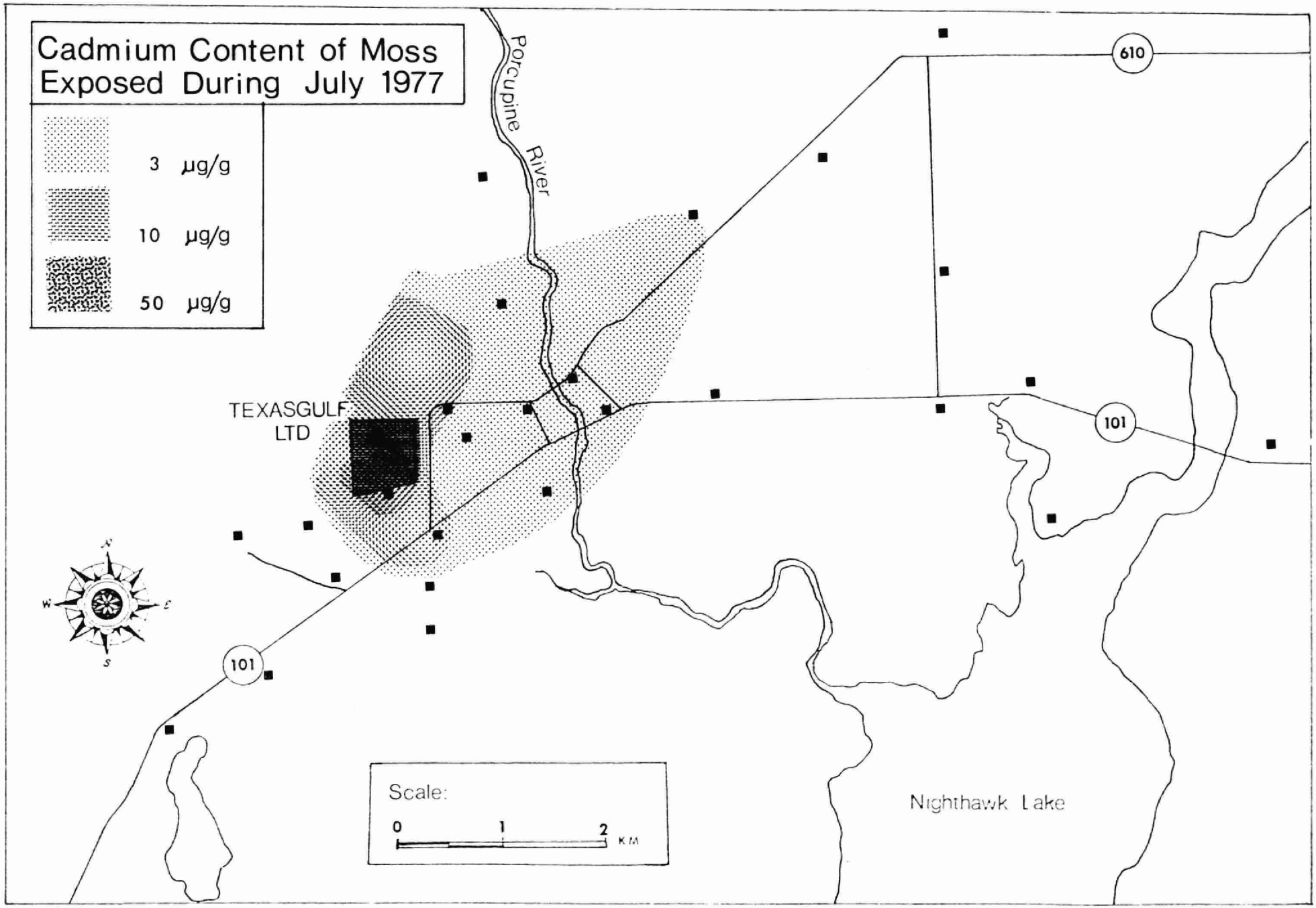

Cadmium Content of Moss
Exposed During July 1977
3 µg/g
10 µg/g
50 µg/g
Porcupine River
TEXASGULF
LTD
610
101
101
Nighthawk Lake
Scale:
0
1
2
KM

Figure 8

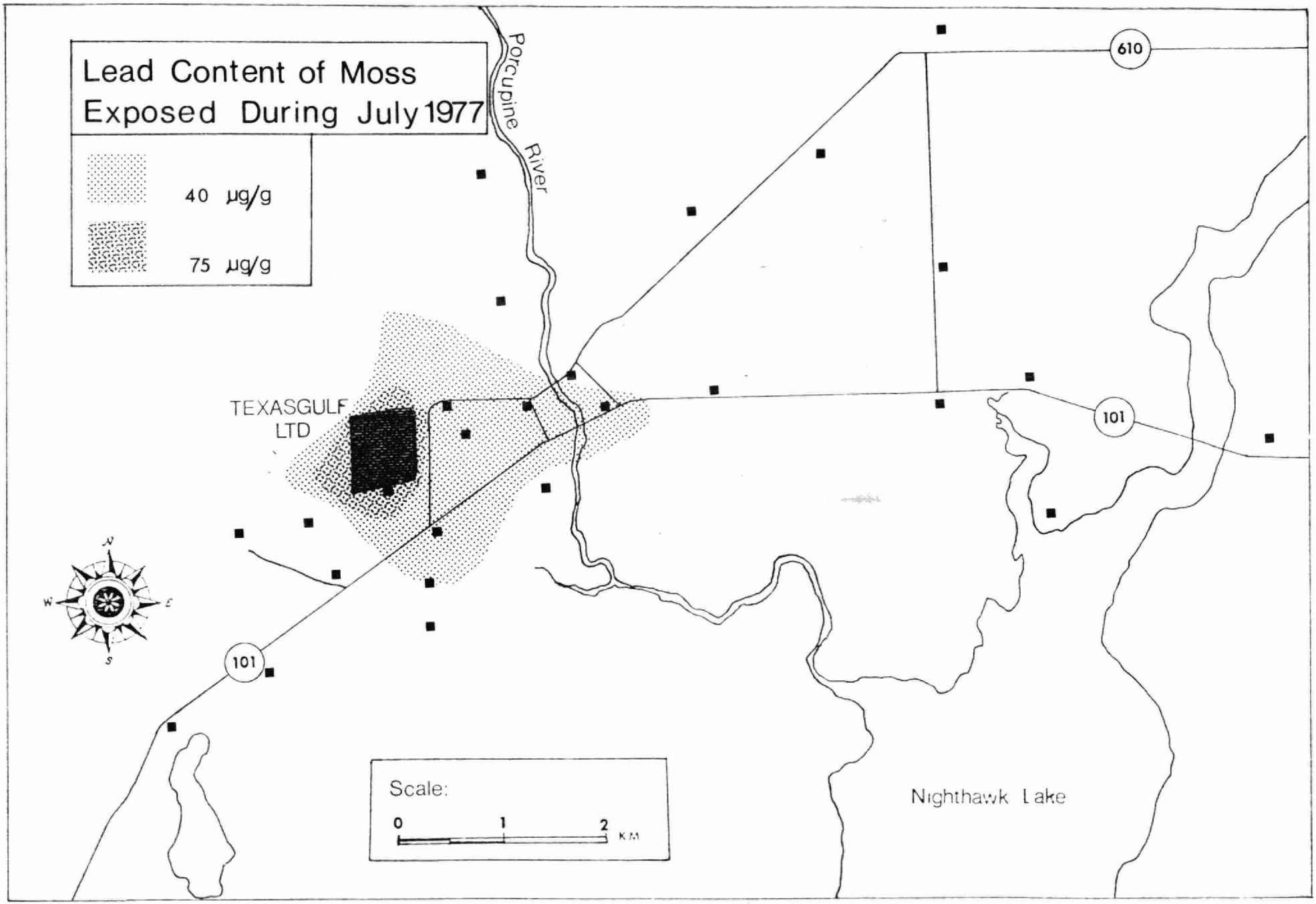

Lead Content of Moss
Exposed During July 1977
40 µg/g
75 µg/g
Porcupine River
610
101
TEXASGULF
LTD
101
Scale:
0
1
2
KM
Nighthawk Lake

Figure 9

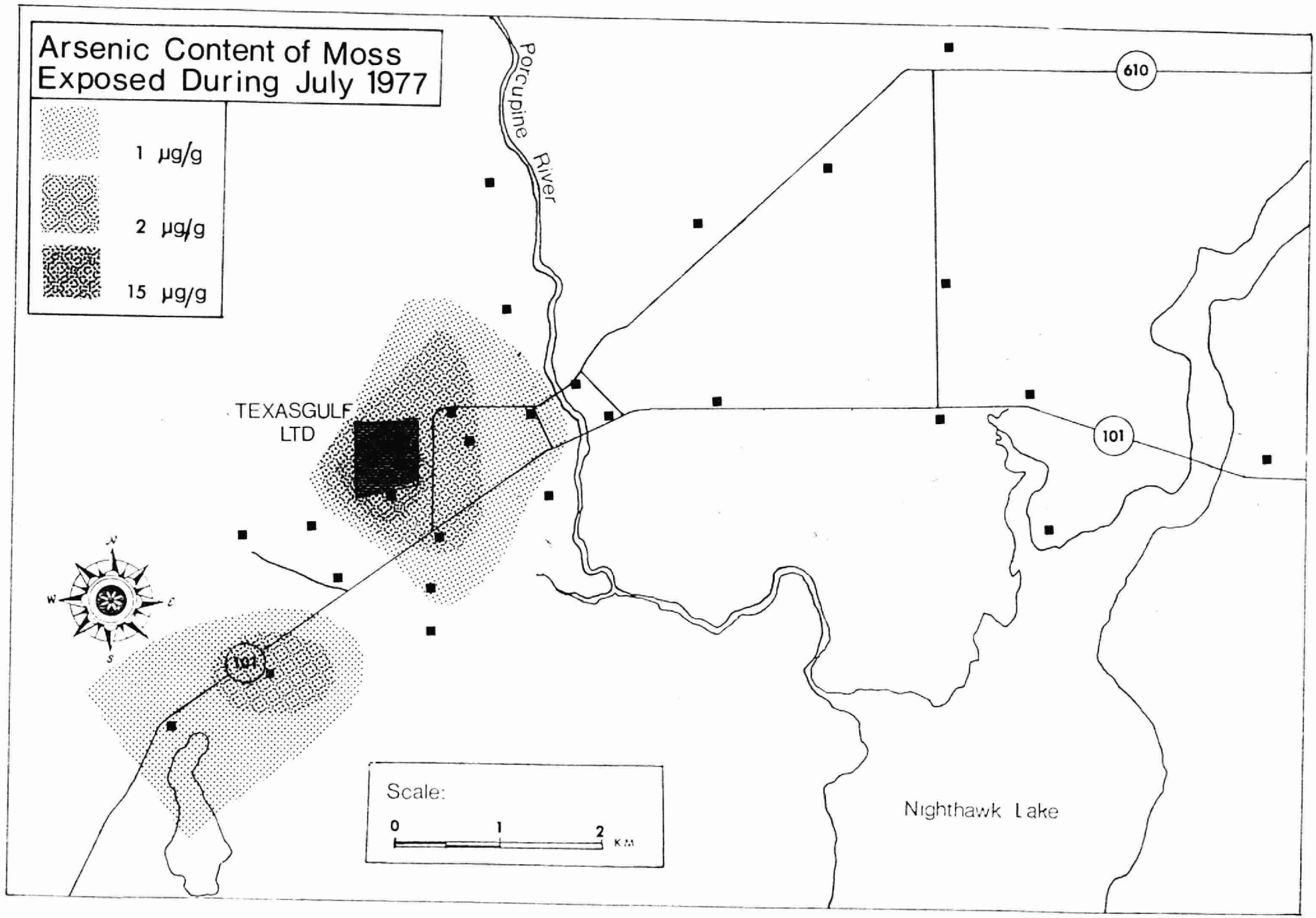

Arsenic Content of Moss
Exposed During July 1977
1 µg/g
2 µg/g
15 µg/g
Porcupine River
610
101
TEXASGULF
LTD
101
N
W
E
S
Scale:
0
1
2
KM
Nighthawk Lake

Figure 10

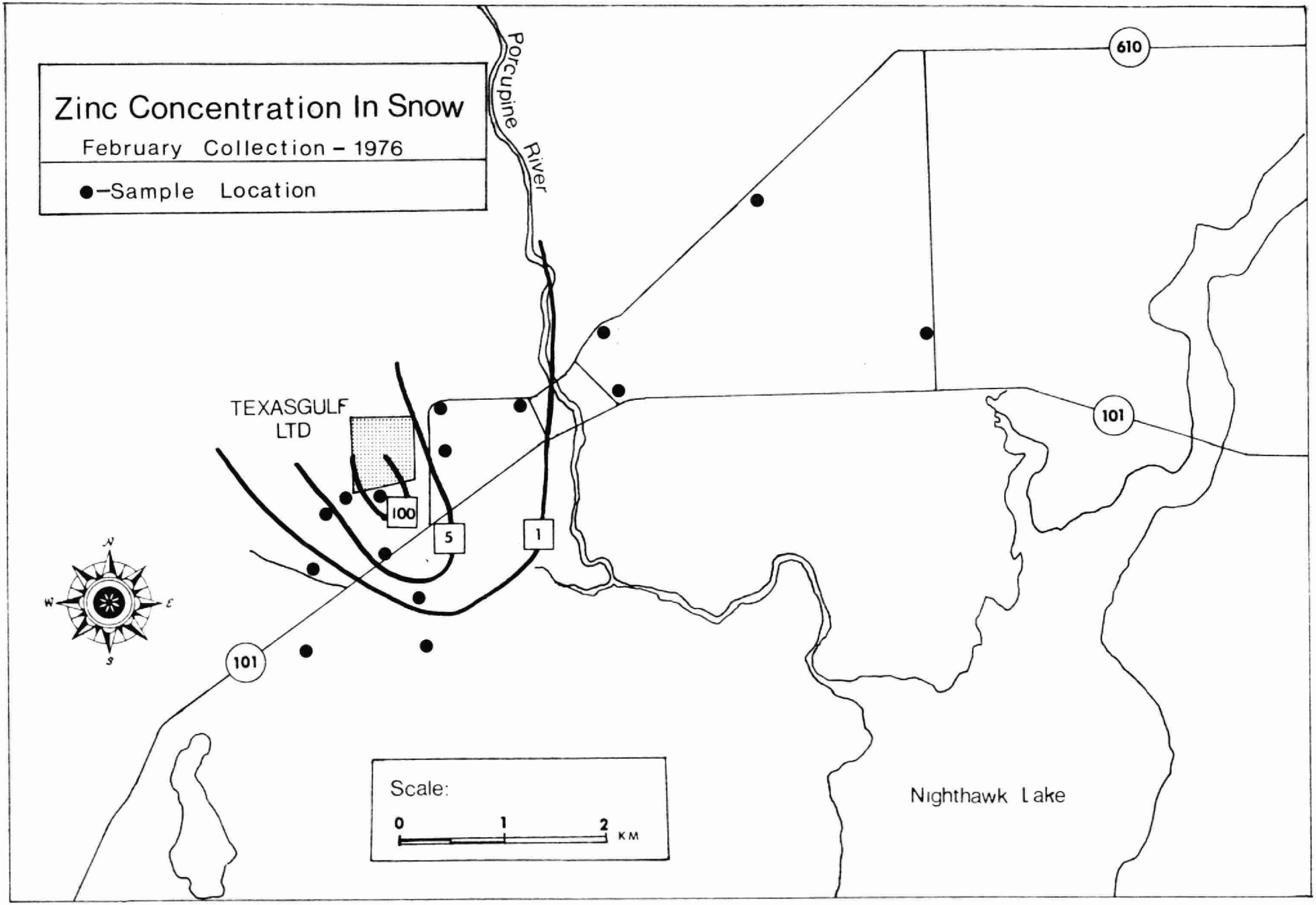

Zinc Concentration In Snow
February Collection - 1976
●-Sample Location
Porcupine River
610
101
TEXASGULF
LTD
100
5
1
101
N
W
E
S
Scale:
0
1
2
KM
Nighthawk Lake

Figure 11

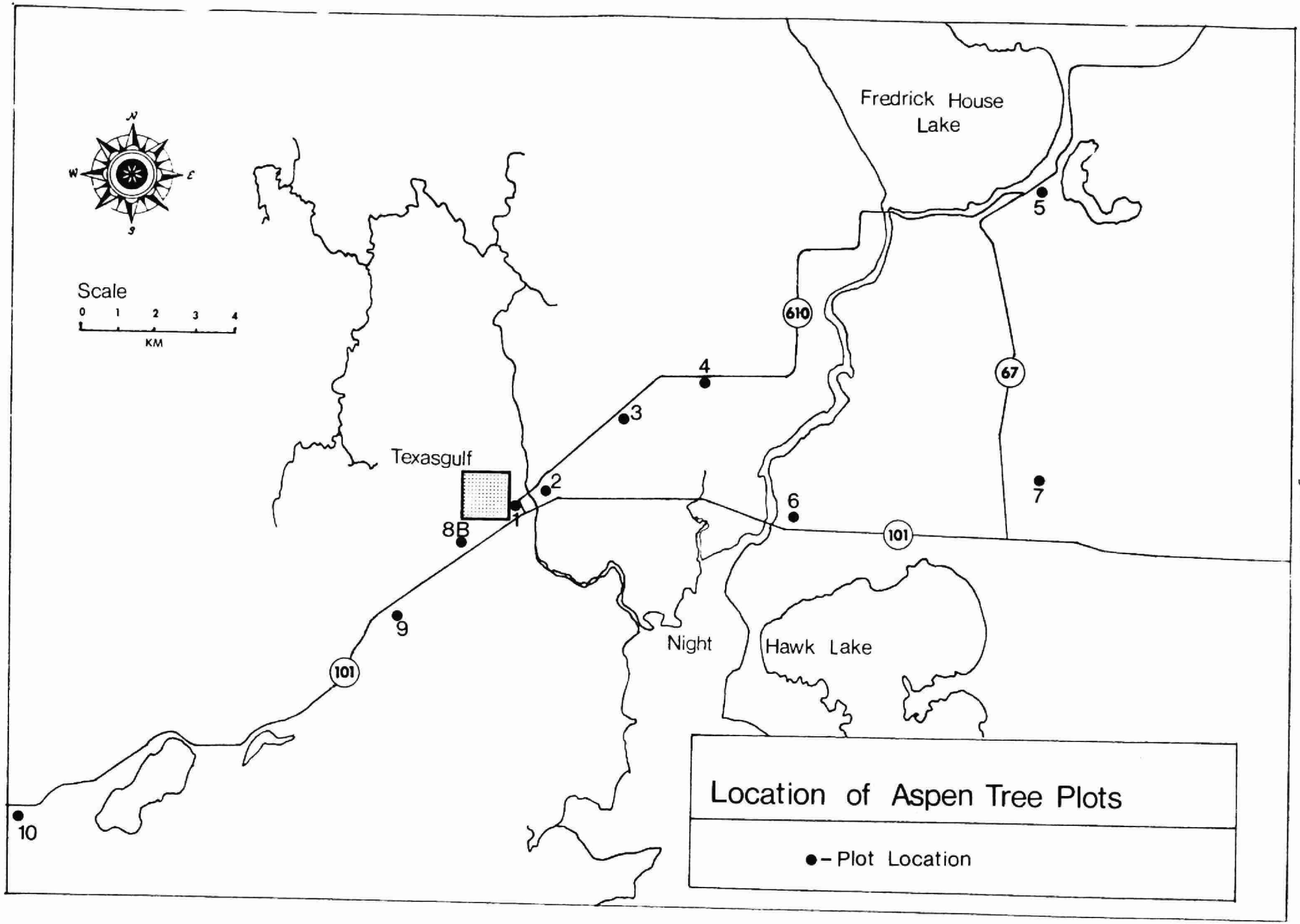
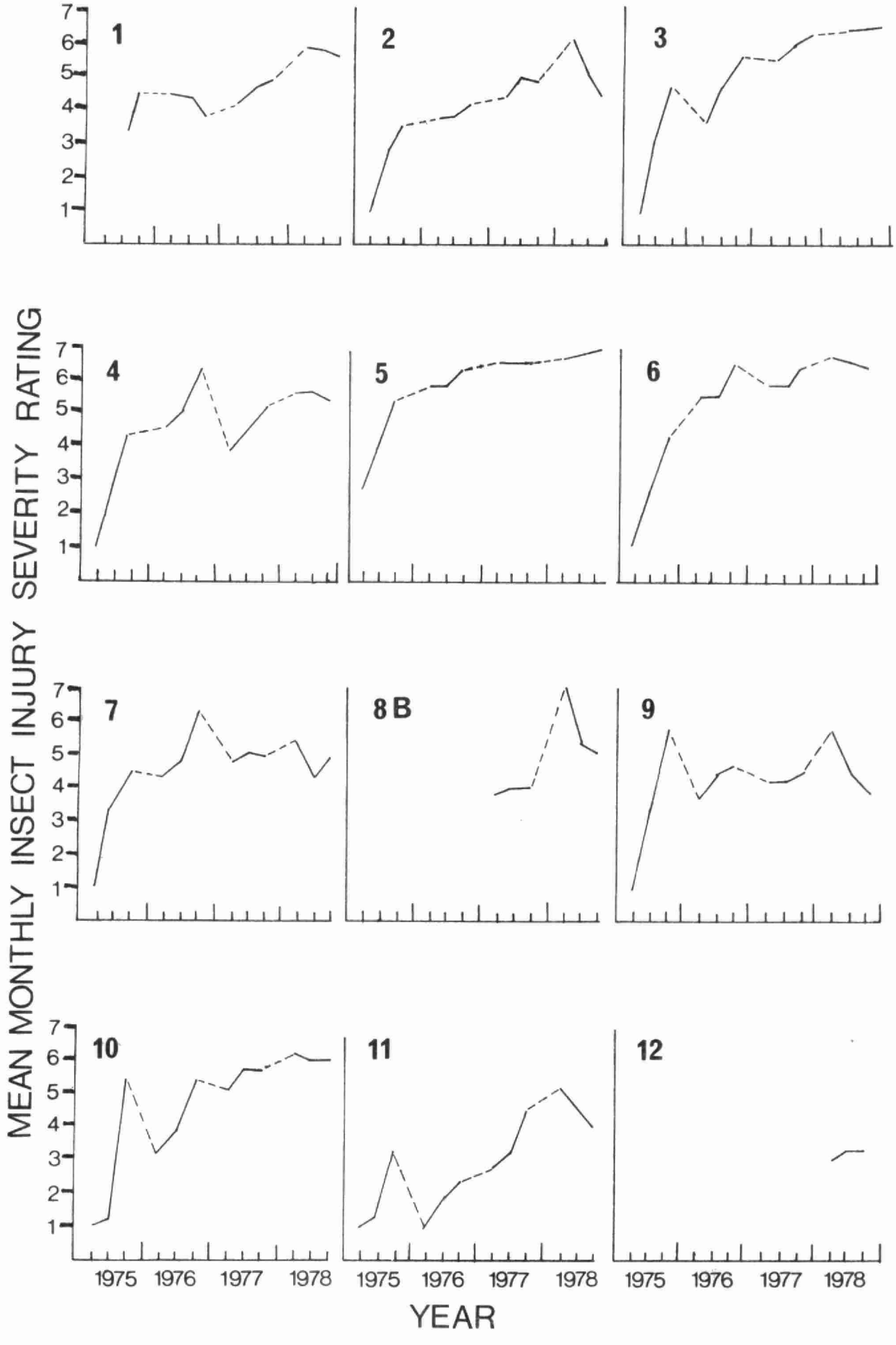

Fredrick House Lake
Scale
0 1 2 3 4
KM
610
67
101
Texasgulf
1
2
3
4
5
6
7
8B
9
10
Night
Hawk Lake
Location of Aspen Tree Plots
● - Plot Location

Figure 12

Figure 13


1
2
3
4
5
6
7
8 B
9
10
11
12
MEAN MONTHLY INSECT INJURY SEVERITY RATING
1975 1976 1977 1978
YEAR

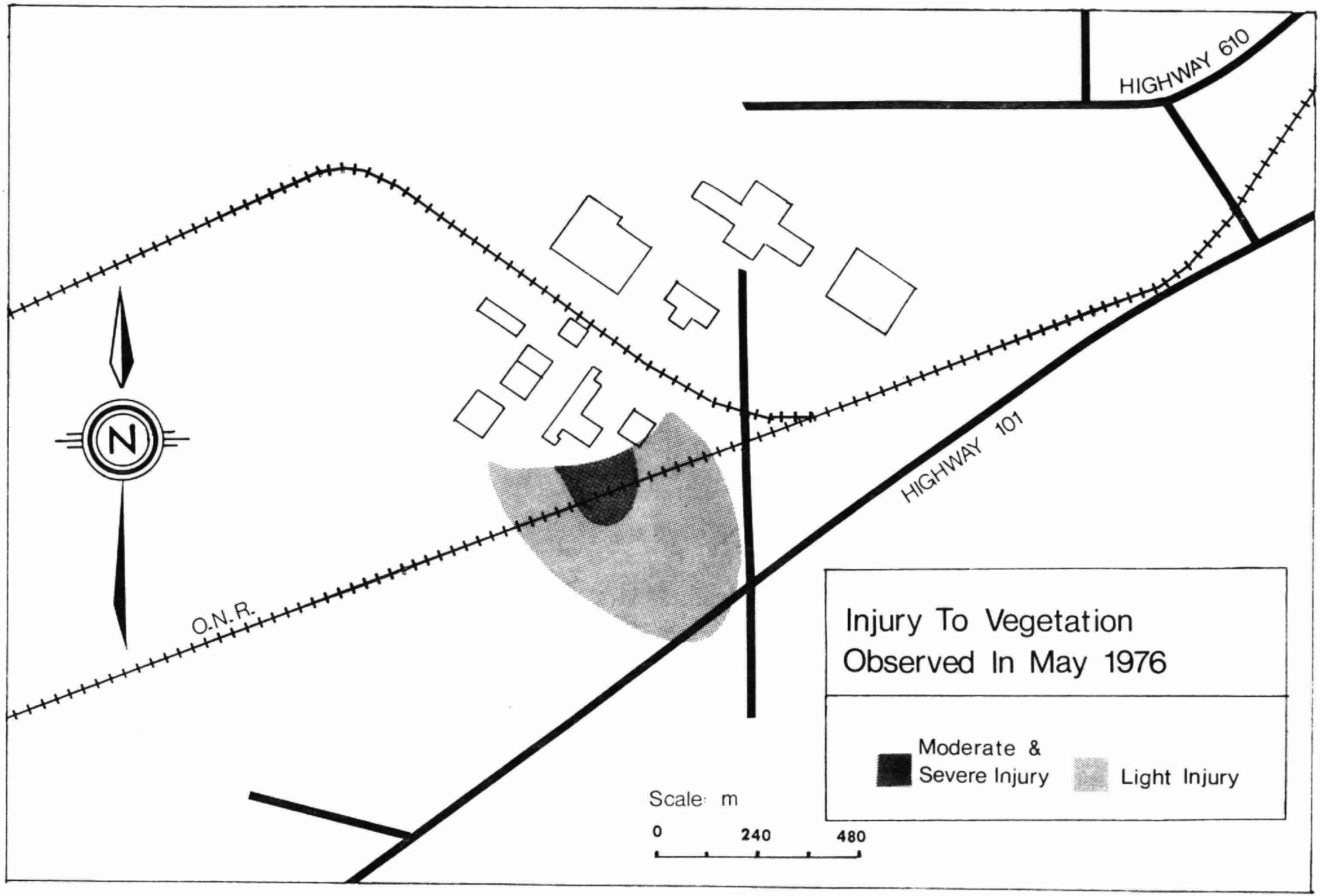

HIGHWAY 610
HIGHWAY 101
O.N.R.
N
Injury To Vegetation
Observed In May 1976
Moderate &
Severe Injury
Light Injury
Scale: m
0
240
480

Figure 14

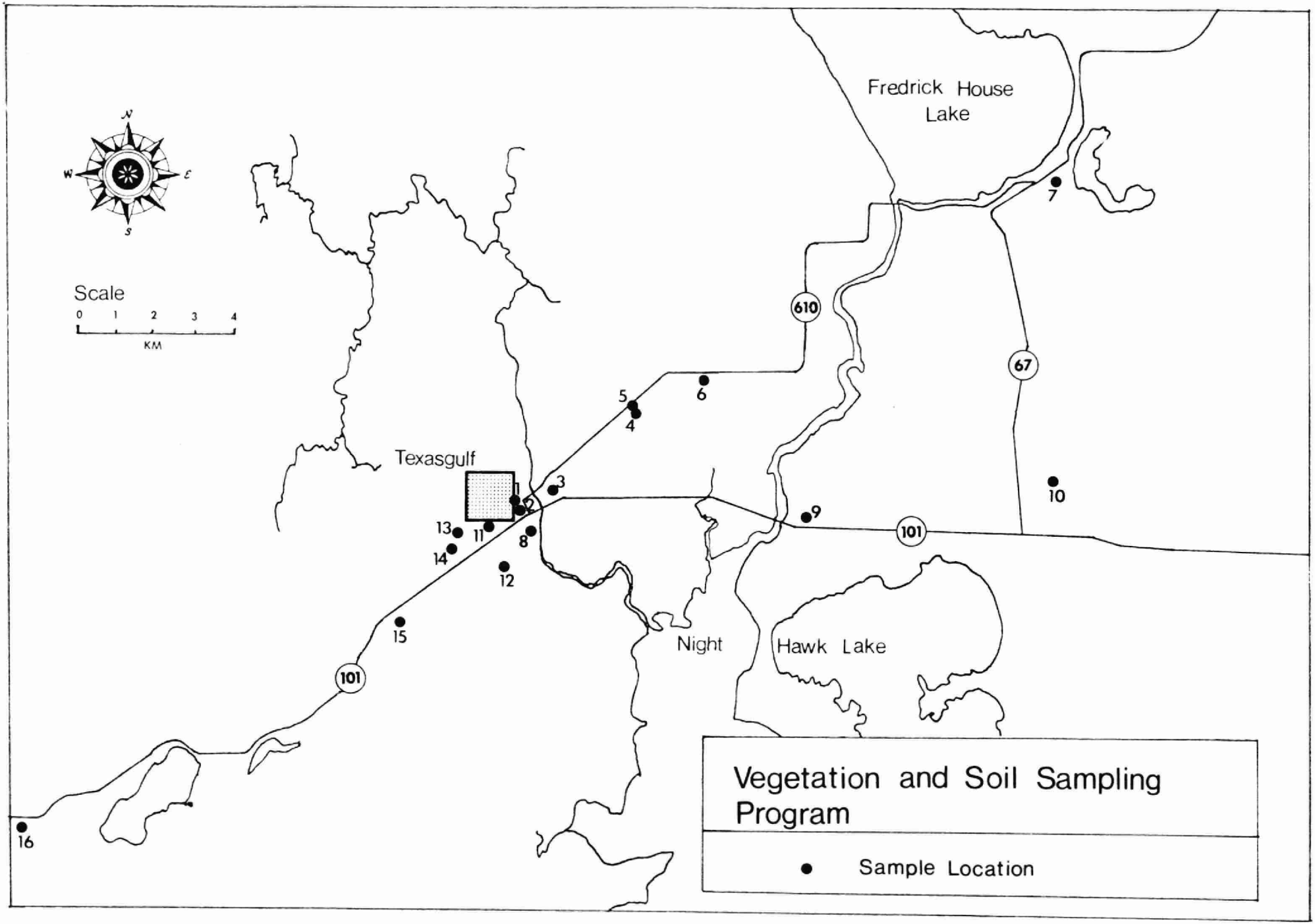

Fredrick House Lake
N
W
E
S
Scale
0 1 2 3 4
KM
610
67
101
101
Texasgulf
Night
Hawk Lake
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Vegetation and Soil Sampling Program
Sample Location

Figure 15

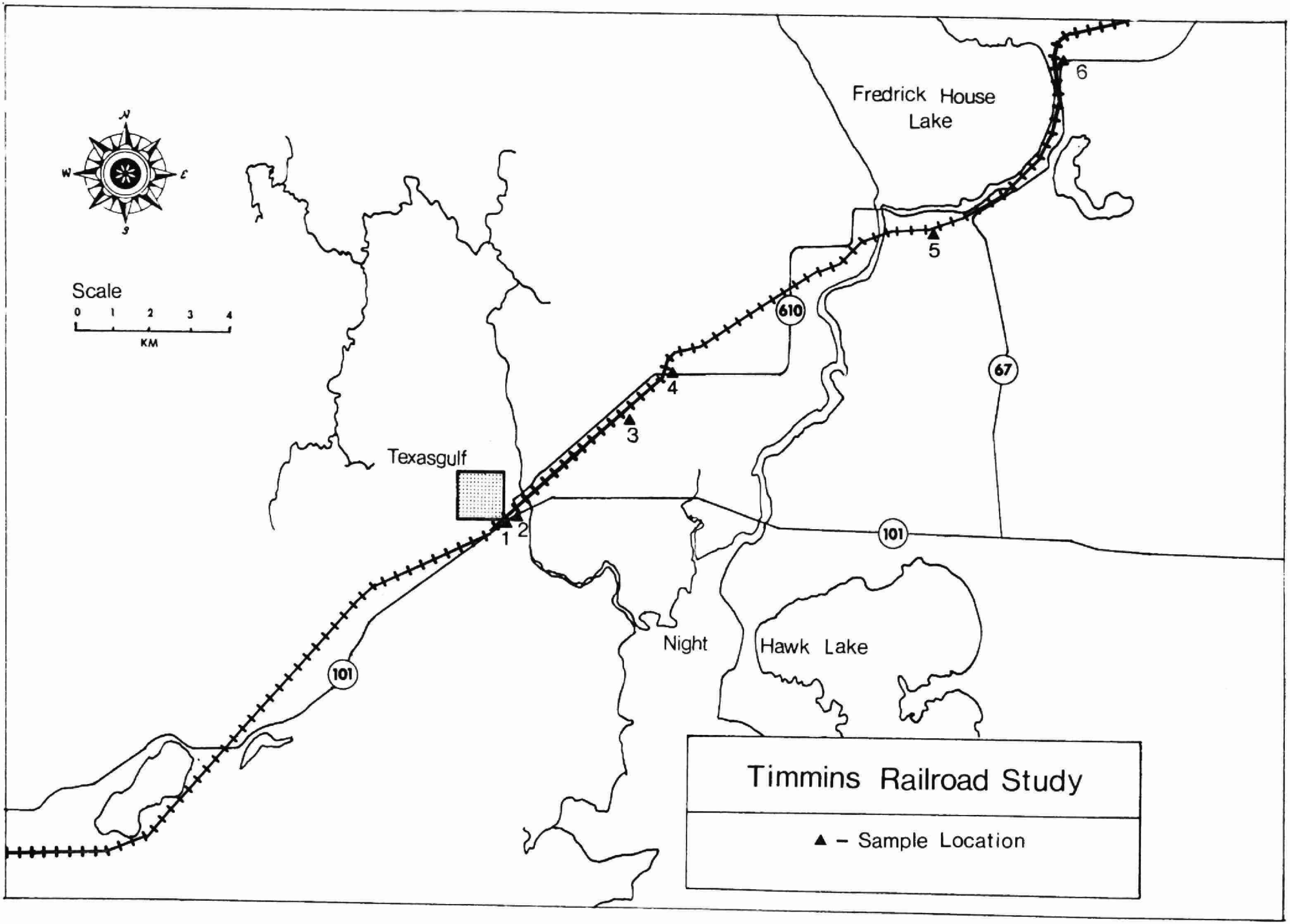
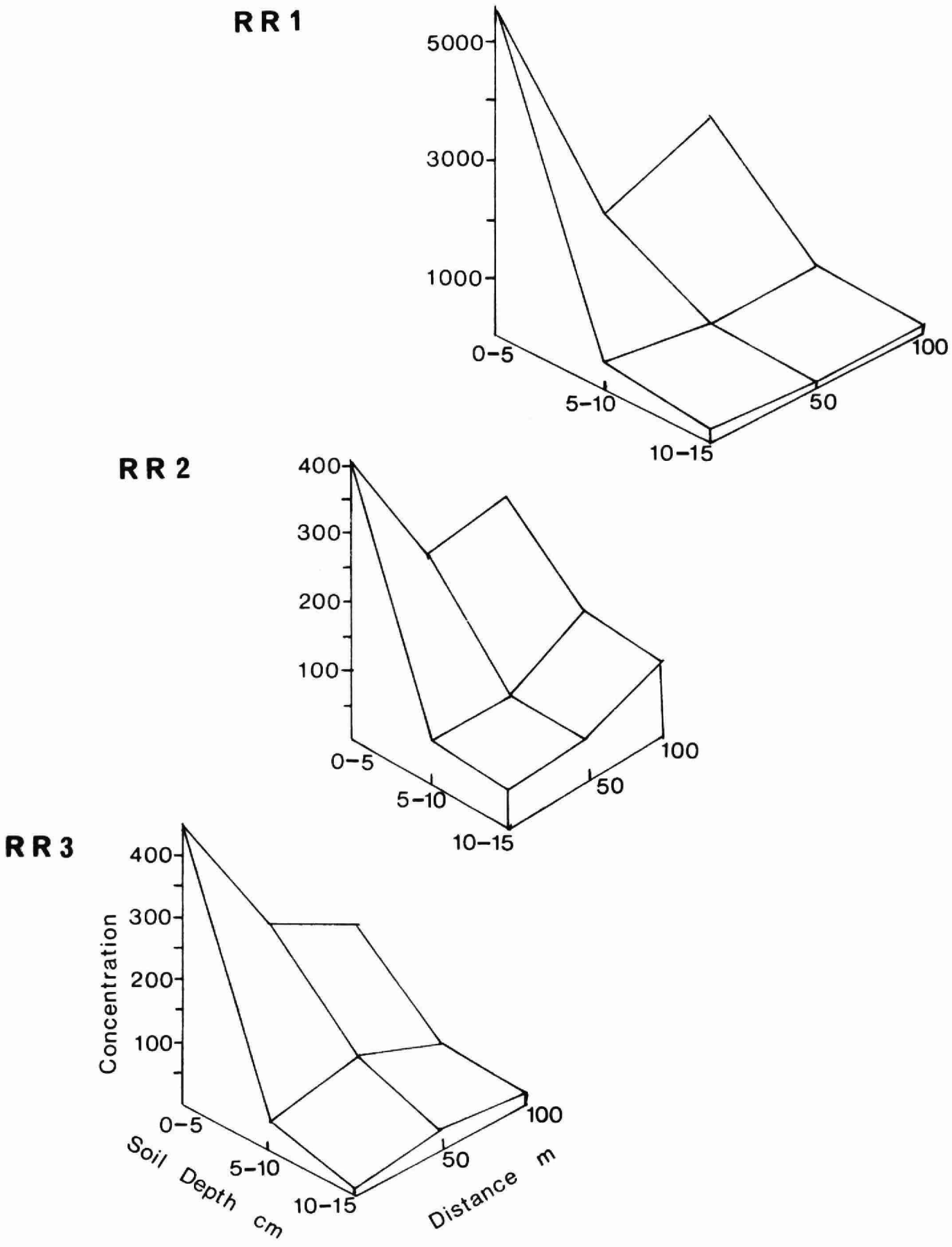

N
W
E
S
Scale
0 1 2 3 4
KM
Fredrick House
Lake
6
5
610
67
4
3
Texasgulf
1
2
101
Night
Hawk Lake
101
Timmins Railroad Study
▲ – Sample Location

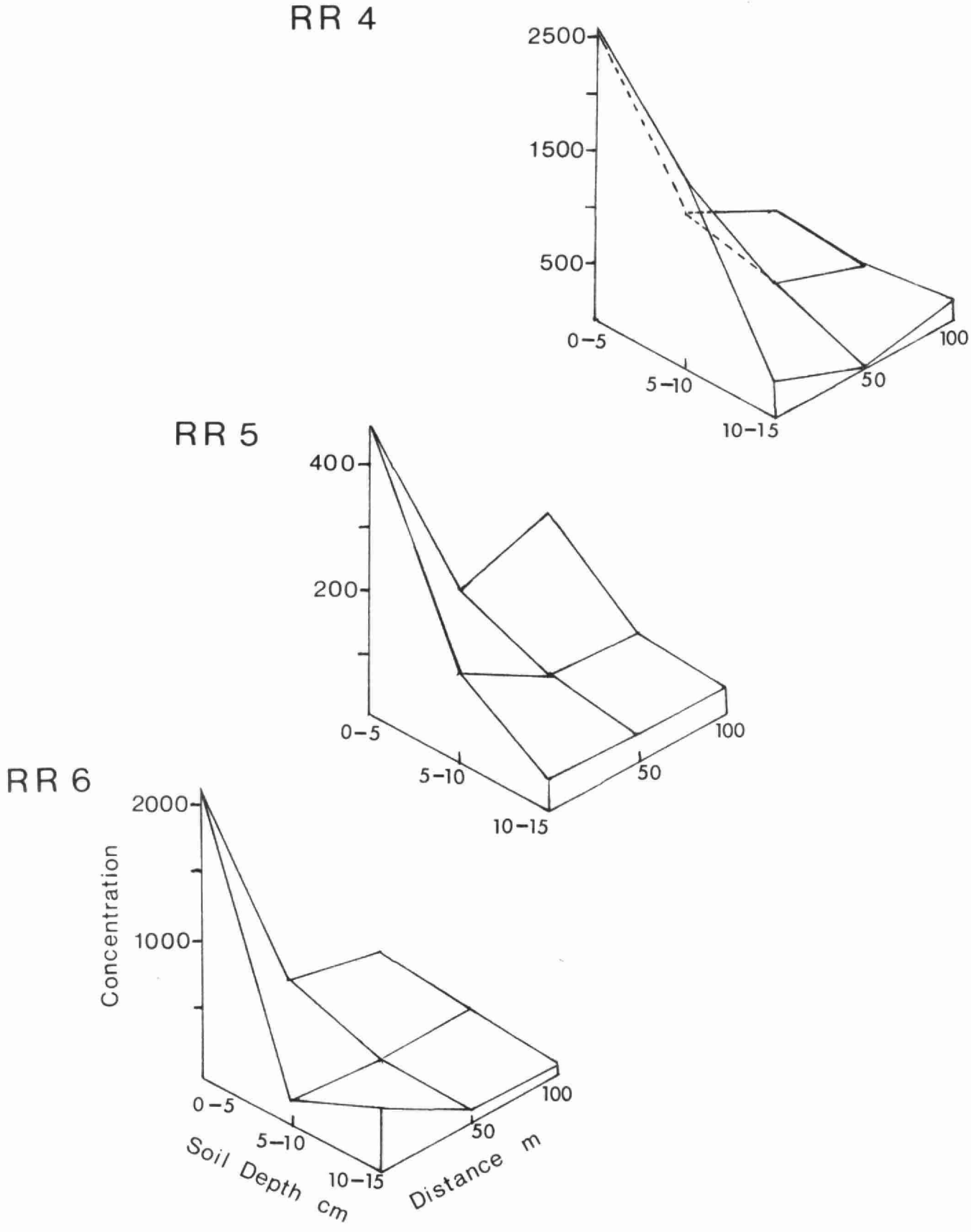
Figure 16

Figure 17



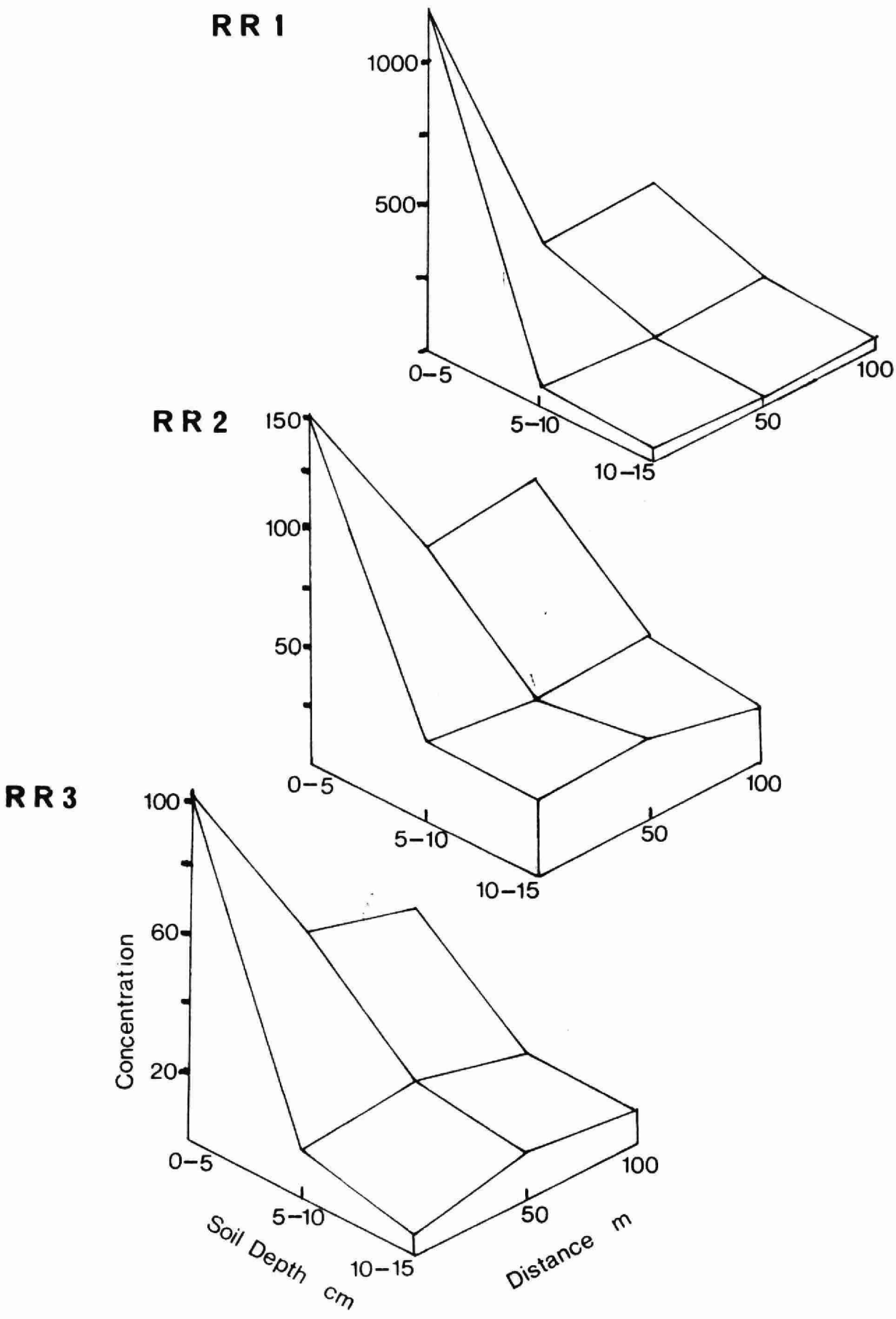
Distribution of Zinc in Soil at Railroad Study Sites 1976

Figure 18



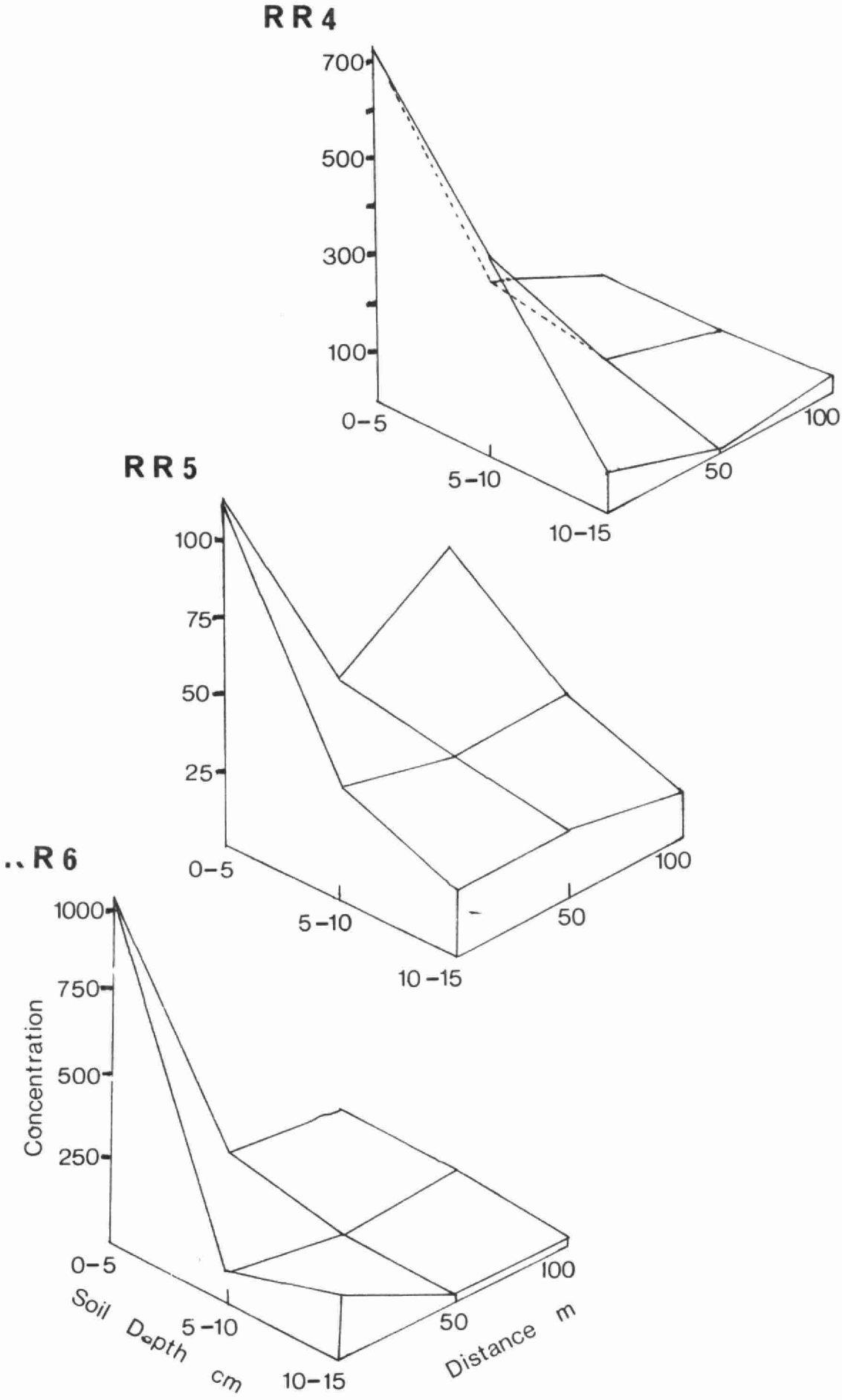
Distribution of Zinc in Soil at Railroad Study Sites 1976

Figure 19



Distribution of Copper in Soil at Railroad Study Sites 1976

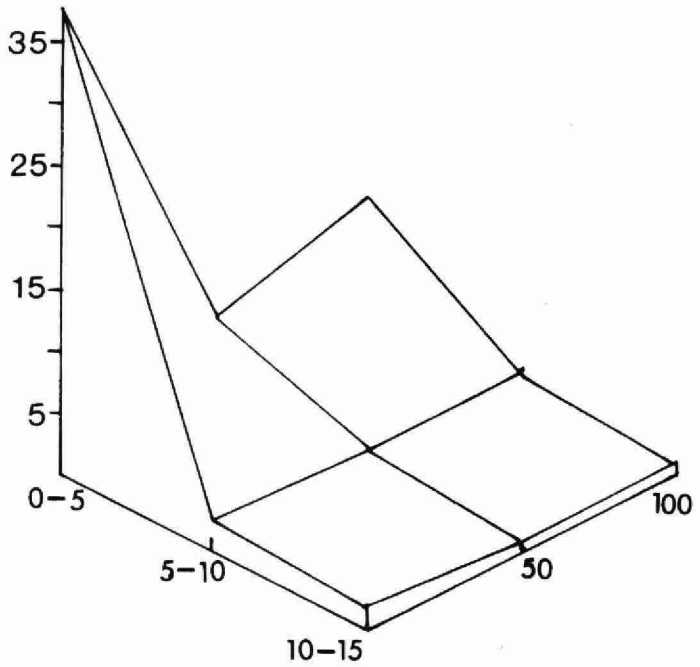
Figure 20



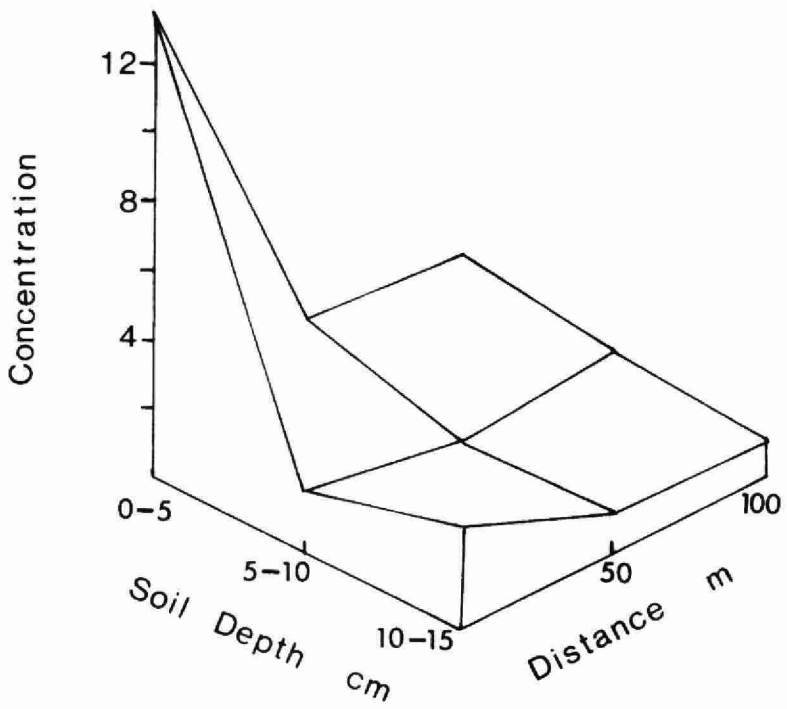
Distributi n of Copper in Soil at Railroad Study Sites 1976

Figure 21

RR 1



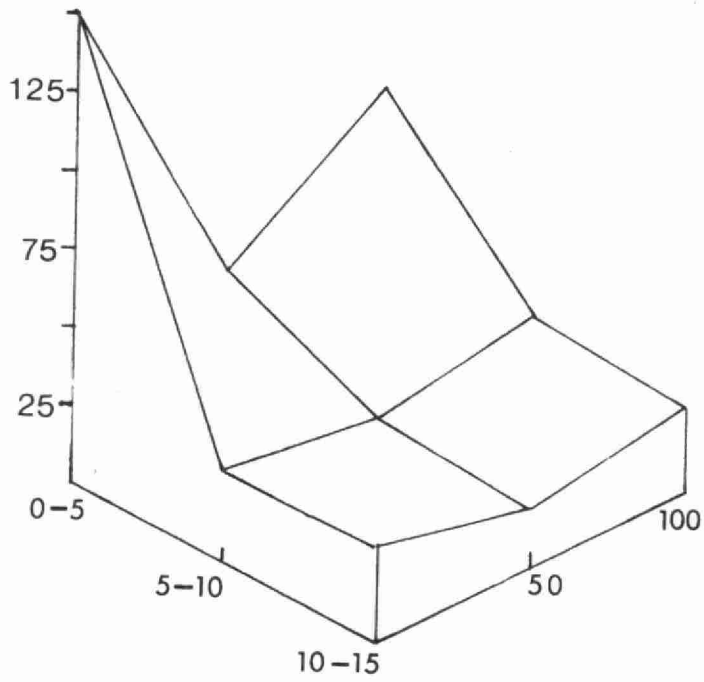
RR 6



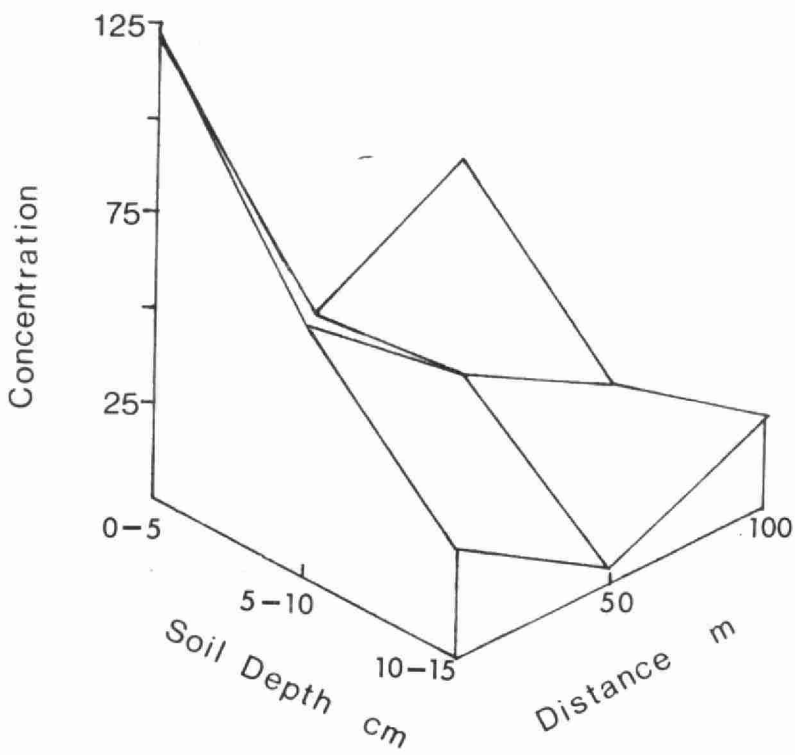
Distribution of Cadmium in Soil at Railroad Study Sites 1976

Figure 22

RR 1



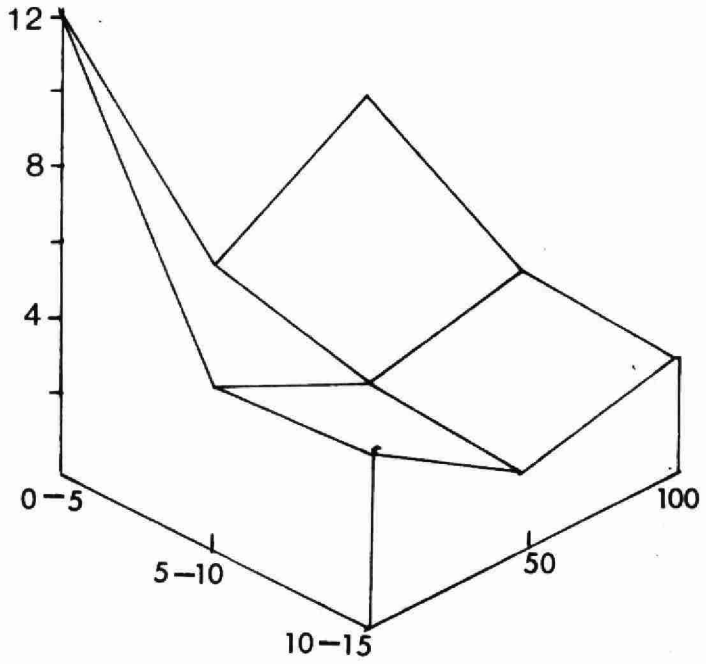
RR 4



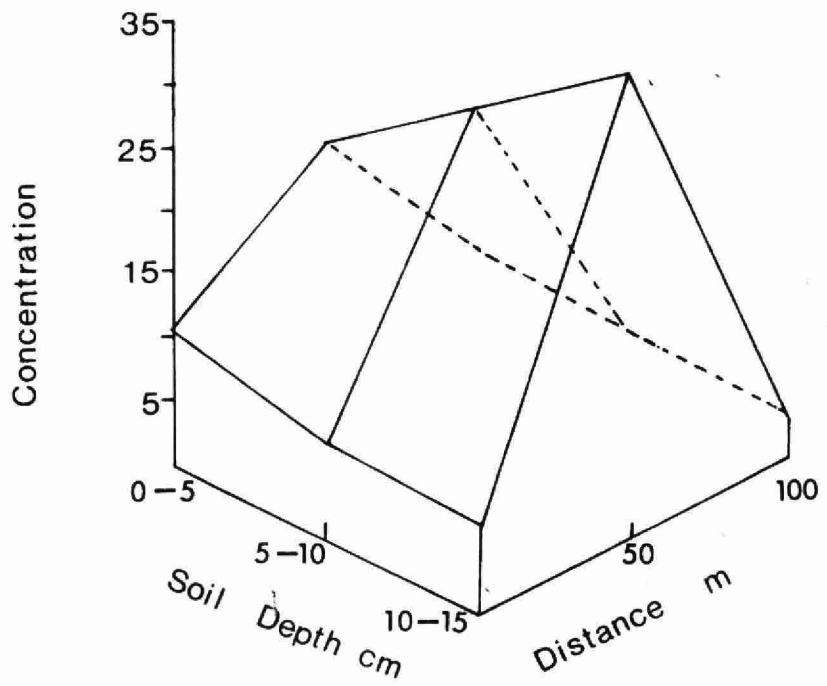
Distribution of Lead in Soil at Railroad Study Sites 1976

Figure 23

RR 1



RR 2



Distribution of Arsenic in Soil at Railroad Study Sites 1976

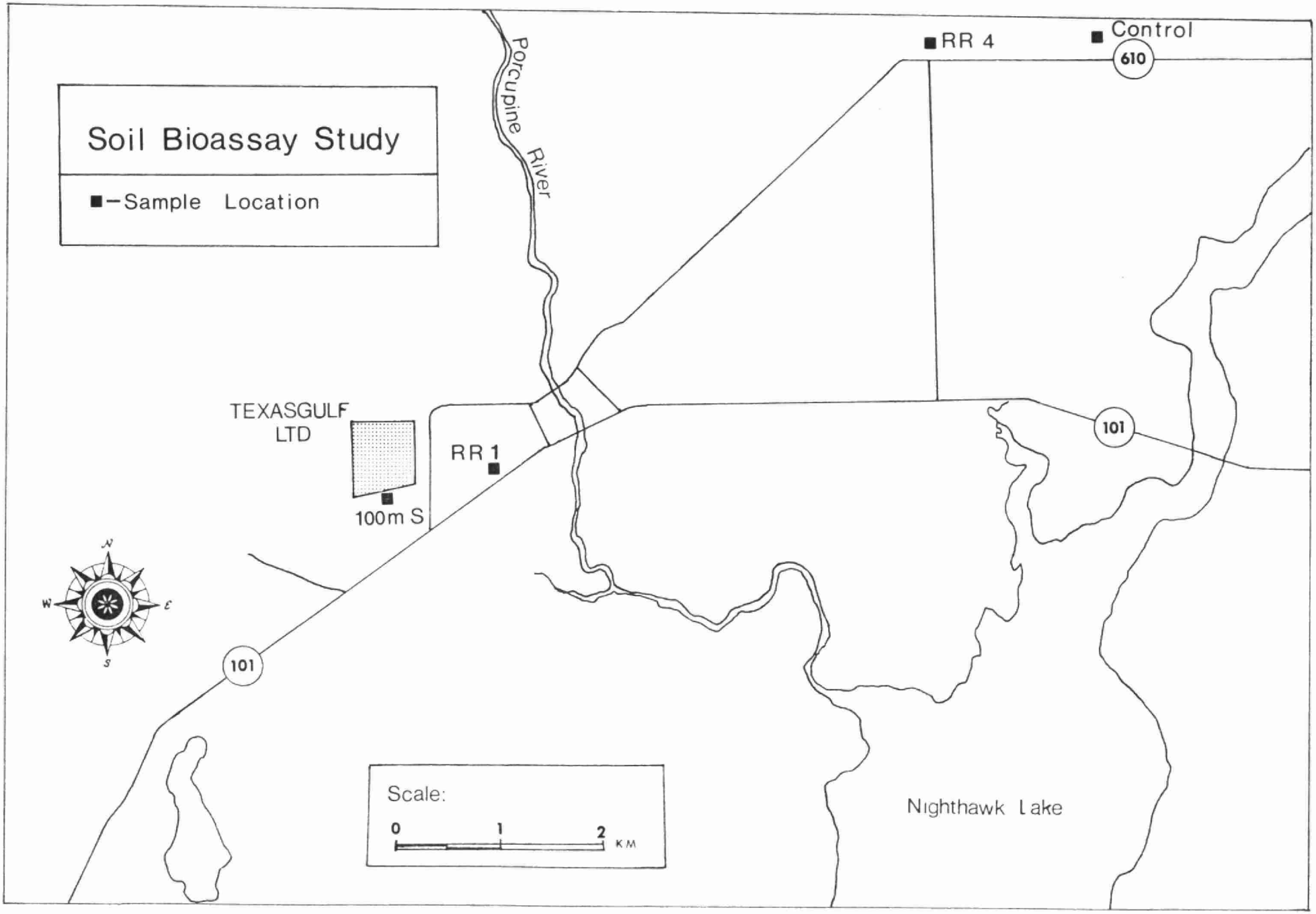

Soil Bioassay Study
■—Sample Location
Porcupine River
RR 4
Control
610
TEXASGULF
LTD
RR 1
100m S
101
101
N
W
E
S
Scale:
0
1
2
KM
Nighthawk Lake

Figure 24

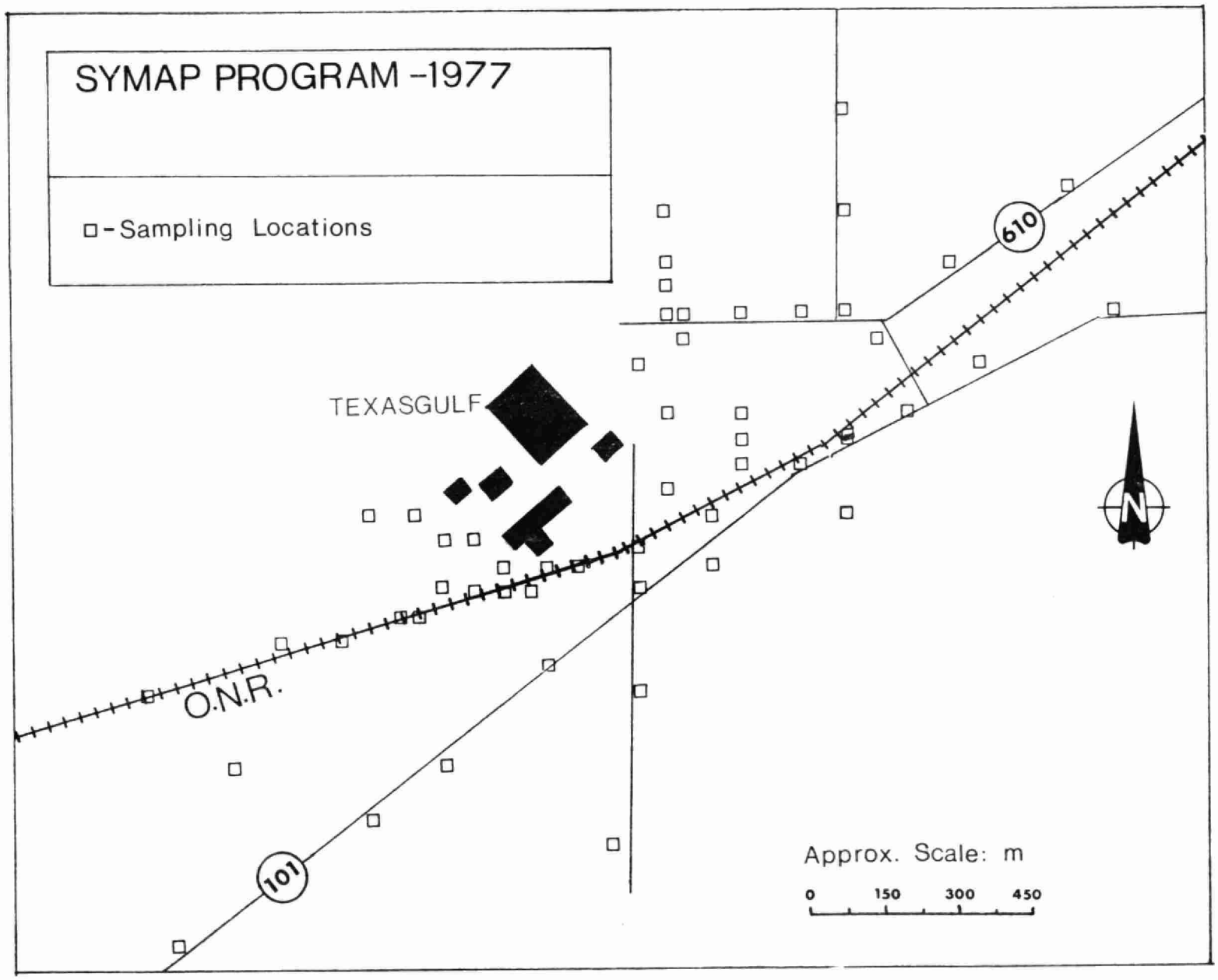

SYMAP PROGRAM -1977
□ - Sampling Locations
TEXASGULF
O.N.R.
610
101
N
Approx. Scale: m
0
150
300
450

Figure 25

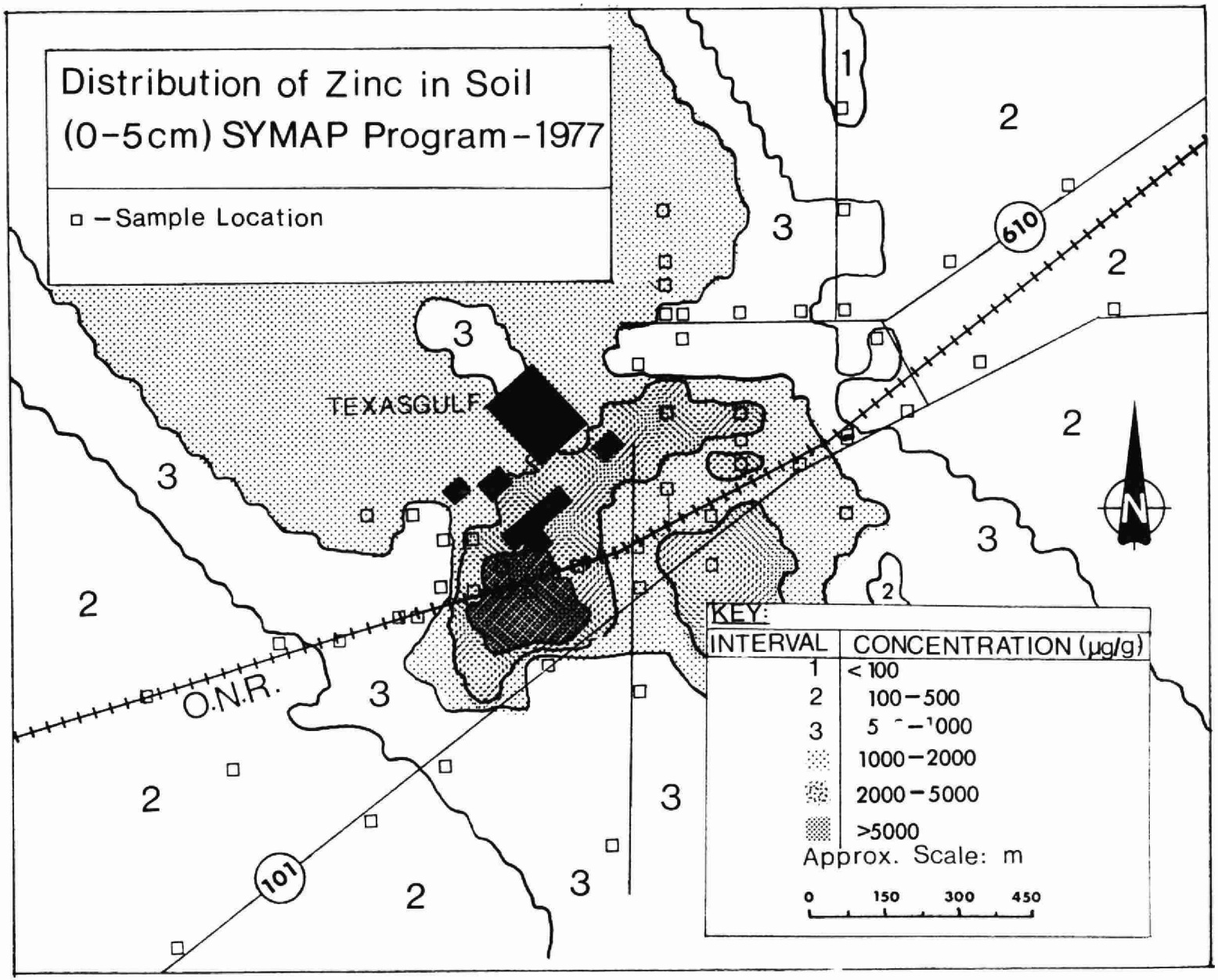

Distribution of Zinc in Soil
(0-5cm) SYMAP Program-1977
□ -Sample Location
TEXASGULF
O.N.R.
610
101
N
KEY:
INTERVAL | CONCENTRATION (µg/g)
1 | < 100
2 | 100-500
3 | 5 -1000
1000-2000
2000-5000
>5000
Approx. Scale: m
0 150 300 450

Figure 26

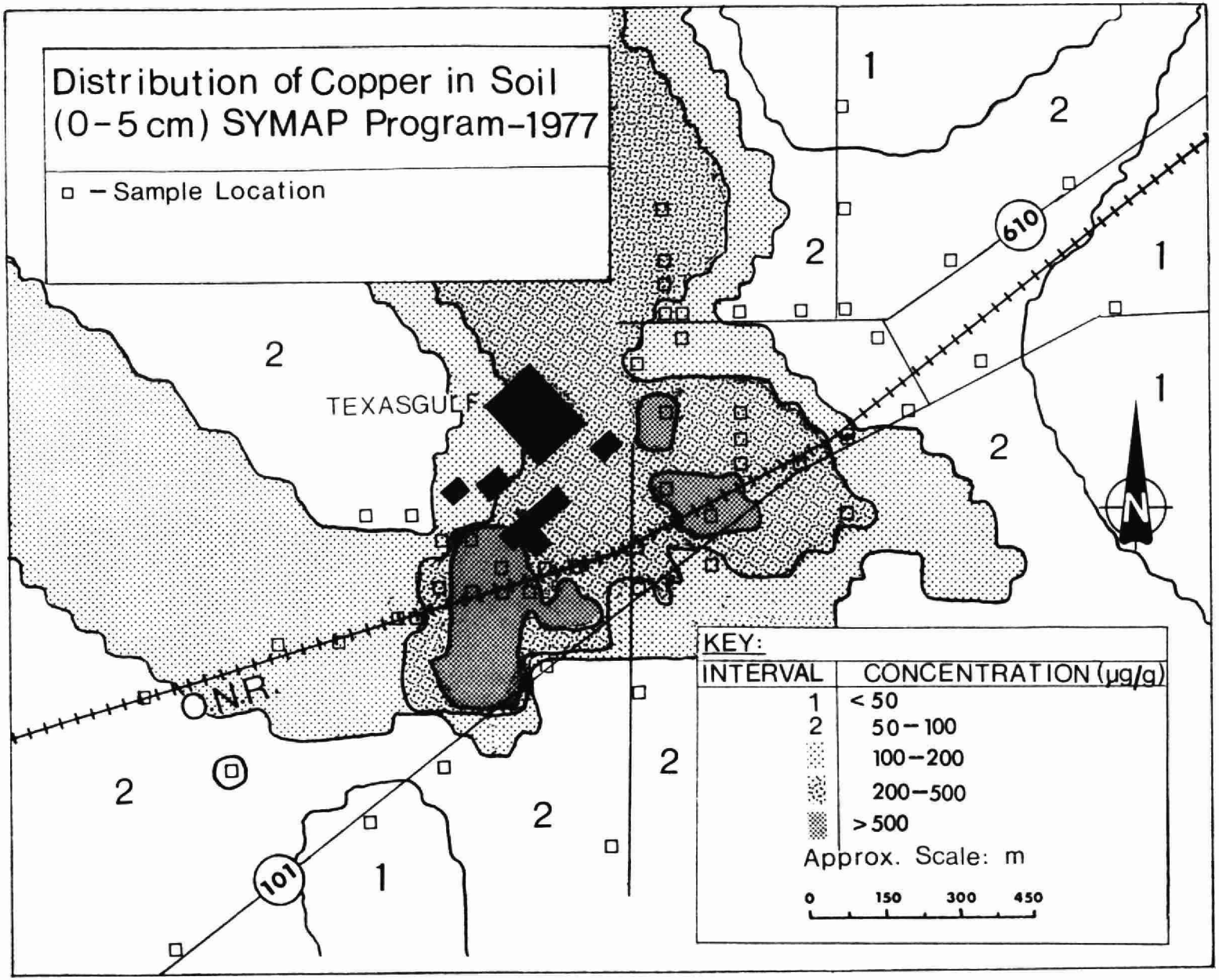

Distribution of Copper in Soil
(0-5 cm) SYMAP Program-1977
□ - Sample Location
TEXASGULF
O.N.R.
610
101
N
KEY:
INTERVAL
CONCENTRATION (µg/g)
1 < 50
2 50-100
100-200
200-500
> 500
Approx. Scale: m
0 150 300 450

Figure 27

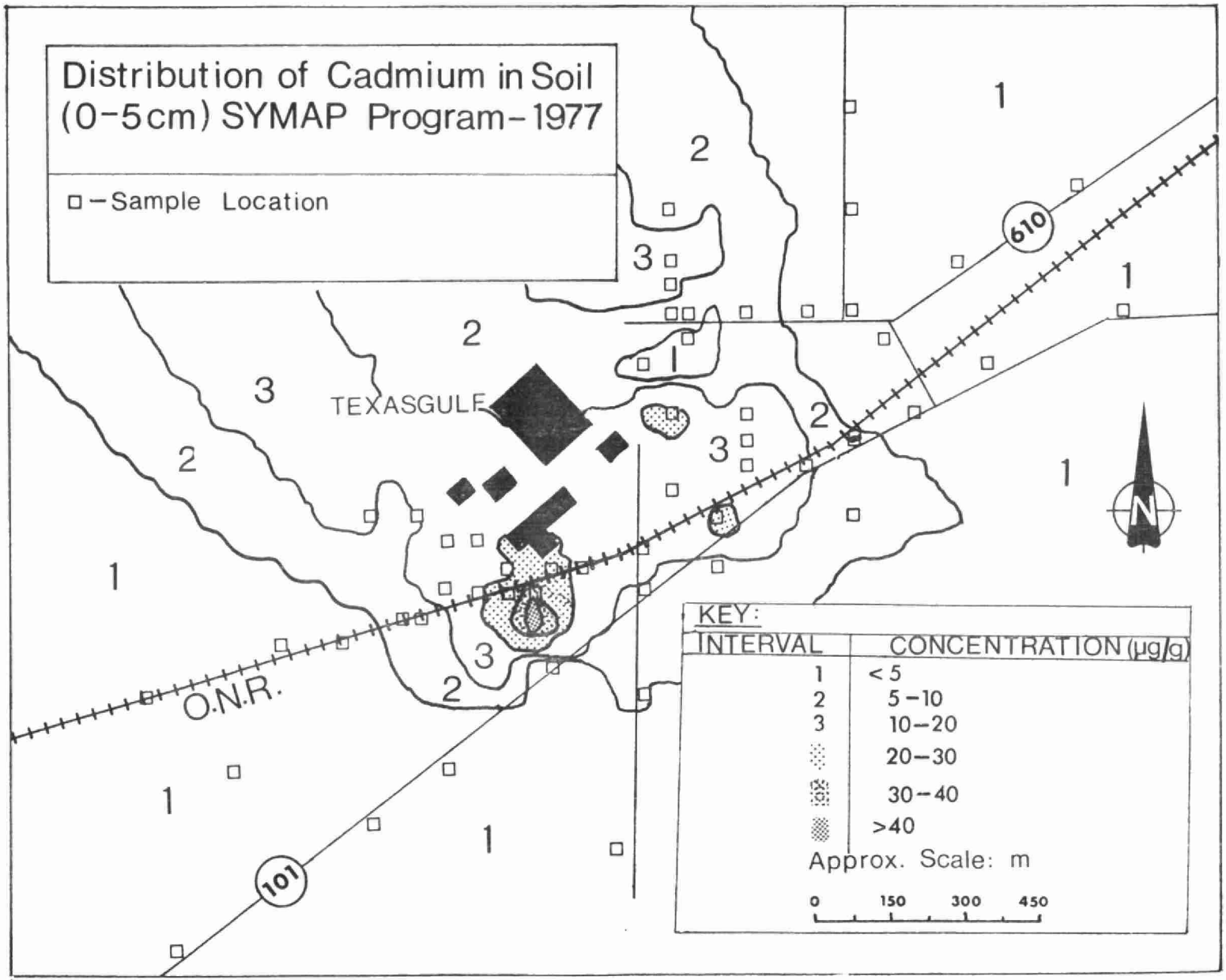

Distribution of Cadmium in Soil
(0-5cm) SYMAP Program-1977
□ - Sample Location
TEXASGULF
O.N.R.
610
101
N
KEY:
INTERVAL
CONCENTRATION (µg/g)
1 < 5
2 5-10
3 10-20
20-30
30-40
>40
Approx. Scale: m
0 150 300 450

Figure 28

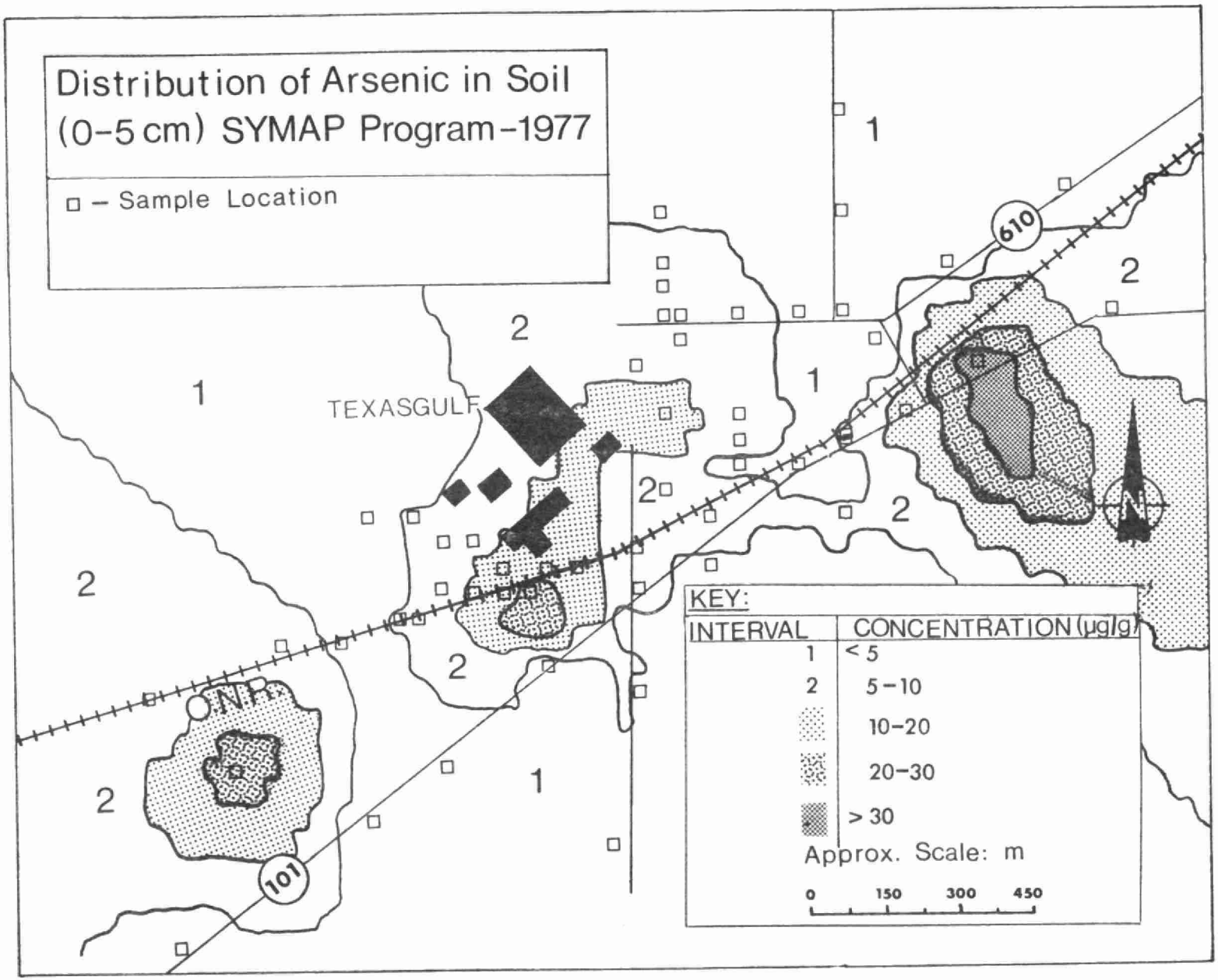

Distribution of Arsenic in Soil
(0-5 cm) SYMAP Program-1977
□ – Sample Location
TEXASGULF
O.N.R.
610
101
KEY:
INTERVAL
CONCENTRATION (µg/g)
1 < 5
2 5-10
10-20
20-30
> 30
Approx. Scale: m
0 150 300 450
N

Figure 29

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